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A REPORT OF FINDINGS FROM A SHORELINE SURVEY IN THE VICINITY OF SEABROOK HARBOR, 1995

And

ASSESSMENT OF THE POTENTIAL FOR FECAL CONTAMINATION OF THE SEABROOK CLAMFLATS FROM BOAT DISCHARGE OF WASTES

A Report to

The New Hampshire Office of State Planning
and
The New Hampshire Division of Public Health Services, Bureau of Food Protection

Submitted by

Dr. Richard Langan and Dr. Stephen H. Jones
Jackson Estuarine Laboratory, University of New Hampshire

July 19, 1995

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SUMMARY

A shoreline survey conducted in June of 1995 in the area adjacent to the Seabrook clamflats indicates that seepage of contaminated effluent from riparian properties could potentially impact the growing area. It is recommended that the Seabrook flat remain closed until these residences are connected to the Seabrook municipal sewage treatment plant.

An analysis of dilution/dispersion of contaminants resulting from potential illegal discharge of wastes from boats in Seabrook Harbor indicates that the number and types of vessels present in the harbor during the fall and winter do not pose a risk of contamination of the clamflats. It is recommended, however, that the Seabrook flats remain closed during the time period when pleasure boats and charter fishing vessels are also present in the harbor (mid-May through September).

INTRODUCTION

A sanitary survey conducted in 1993 and 1994 in the Hampton Harbor Estuary, New Hampshire, resulted in the conditional opening by the NH SSCA (State Shellfish Control Agency; the NH Division of Public Health Services) of the Common Island and Browns River clamflats for recreational harvest. Despite water quality records from the survey period at sites in the vicinity of the Seabrook clamflats or "middle ground", that met conditionally approved classification criteria, the Seabrook flats remained closed due to the close proximity of residences with suspected malfunctioning septic systems and the location of boat moorings in Seabrook Harbor. Results of the continuing sampling program in the fall through spring of 1994-1995 indicated that fecal coliform counts remained low in Seabrook Harbor (east side of Seabrook flats), however several samples in the channel to the West of the Seabrook flats had elevated (>43 FC/100ml) coliform counts. It was suspected that the sources of these intermittent, elevated water scores were septic systems in the vicinity of River Street and/or Cross Beach in Seabrook. Since these sources will be eliminated sometime in the fall/winter of 1995-1996 when the Seabrook Sewage Treatment Plant goes on line, it was determined by the NH CORD Shellfish Committee that it would be important to confirm that these sources of pollution were indeed responsible for the variability in FC counts. The committee agreed that a period of documented improvement in water quality at sample sites following the start of operation of the Seabrook STP (and hence elimination of the River Street/Cross Beach pollution sources) could result in opening of the Seabrook flats. The one remaining concern was the moored vessels in Seabrook Harbor and the lack of information on dilution and dispersion of contaminants associated with potential unlawful discharge of wastes from the vessels.

Section C 9 of Part I of the National Shellfish Sanitation Program (NSSP 1993) Manual of Operations requires than an analysis of the impact of marinas or mooring areas on adjacent shellfish growing waters be conducted before the area can be properly classified. It was determined by the CORD Shellfish Committee that in addition to revisiting the shoreline adjacent to Seabrook Harbor, that a marina dilution study be conducted as well.

This report describes the results and findings of the shoreline survey work conducted in June 1995 and the modeling of dilution/dispersion of contaminants resulting from vessel discharge of wastes in Seabrook Harbor.

METHODS

1. Shoreline survey in the vicinity of Seabrook Harbor

On June 2, Andrea Tomlinson and Deborah Lamson of the Jackson Estuarine Laboratory conducted a shoreline survey for properties adjacent to Seabrook Harbor. All properties were inspected for the presence of pipes, effluent, suspected malfunctioning septic systems and any other potential sources of pollution to the growing area. Samples for fecal coliform analysis were obtained from those properties with visible effluent and from the adjacent harbor area.

2. Dilution/Dispersion modeling of wastes discharged from vessels in Seabrook Harbor

A. Information Gathering

The study was initiated by gathering information on: 1) the number and types of vessels moored or docked in Seabrook Harbor; 2) accurate bathymetry and water volumes in the harbor; and 3) circulation of water in the vicinity of the clamflat

1) Vessel information was obtained by researching records on mooring permits at the New Hampshire State Port Authority, examining aerial photographs of the mooring areas in the Harbor, a site visit and photographs of mooring locations and types of vessels, and conversations with the Port Authority Director and the Seabrook Harbor Master.

2) Bathymetry and water volumes were obtained from charts provided by the NH Department of Transportation. The charts resulted from the 1993 dredging of

Seabrook Harbor and provided accurate depths and dimensions of the Harbor. Volumes were calculated using the DOT data and NOAA tidal height data for Hampton Harbor.

3) Data on water circulation and movement was obtained from the current study conducted in June of 1994 as part of the 1993-1994 Sanitary Survey of Hampton harbor. In that study, current speed and direction were measured at two stations in Seabrook Harbor during four intervals each of the ebb and flood tides.

B. Modeling

Based on the alignment of the moored vessels in the Harbor, the initial thought was that discharge from the vessels could be equated to discharge from a multiport diffuser pipe, and the EPA discharge models MERGE and CORMIX models could be applied to this situation. Since CORMIX is a more robust model than MERGE in terms of predicting plume concentrations in the far field, it was was chosen for use in this study. Though many of the assumptions needed to fit the CORMIX model were applicable to this situation, both CORMIX and MERGE are designed for continuous discharge, and therefore not a perfect fit for discharge from moored vessels. In order for the model to fit, it was assumed that all vessels in the area were discharging 2 $\times 10^9$ FC in 12 liters of water over a six hour period. Though this assumption is conservative in that it assumes every vessel is illegally discharging waste in the same six hour period (a highly unlikely scenario) it also assumes that the discharge is slow and continuous, which is also highly unlikely.

In order to better simulate the discharge from a vessel, an advection/dispersion evaluation of a slug injection was used, and the same conservative assumption that each vessel would discharge wastes from one person over a six hour period (however, as a slug discharge) was used. The objectives of the models were to predict the concentration of fecal coliforms in the discharge plume when it comes in contact with the clamflat.

The models were initially run at a worst case scenario; discharge beginning at slack low tide and continuing through the flood tide and treating coliform bacteria as conservative particles. If a discharge occurs during the ebbing tide, except during the slack periods at high or low tides, the longitudinal dispersion due to the ebb tide current velocity carries the plume out of the Seabrook Harbor area without intersecting with the clamflats. Additionally, ebb tide waters flow over the clamflats in a northeasterly direction, resulting in a directional dispersion of any discharge plume from moored vessels away from the clamflats. At slack low tide, however, the incoming water "dead ends" at the southern terminus of Seabrook Harbor until the water is sufficiently high to flow over the clamflat. Vessel discharge of contaminants at this point in time was considered to be the worst case scenario for impact on the clamflats. The initial run of the model assumed a minimum longitudinal dispersion coefficient (low tidal current velocity of 0.10m/sec), an equal lateral dispersion coefficient (current velocity = 0.1 m/sec) , the least volume dilution low tide, and did not take a decay coefficient (bacterial die-off) into consideration. A subsequent run of the model used more accurate current velocity and directional vectors as well as conservative decay coefficient for bacterial die-off.

Decay of fecal-borne bacteria in seawater occurs over a wide range of rates, depending on the prevailing environmental conditions. Grazing by bacterivores and sunlight have the most significant impacts on bacterial survival, and rates are decreased ~2x with each 10°C increase in temperature. Solic and Krstulovic (1992) looked at the effects of radiation, temperature, salinity, & pH on fecal coliform survival. They used non-turbid seawater and found no impact on T90 (time for 90% of bacteria to die) at depths to 10 m (T90~5 h). The die-off rate was doubled at 20 vs 10°C. In sunlight at 35 ppt NaCl and ~20°C, they found die-off rate to be 1.02/h. Pommepuy et al. (1992) measured fecal coliform T90 values of <2 h under high sunlight conditions in the Mediterranean Sea. Sorensen (1991) found *E. coli* to have a half life of ~ 5 h, or 3.3/d, in raw seawater. Valiela et al. (1991) used literature values to estimate fecal coliform death rates in Buttermilk Bay, MA. The high rate of death, based on a T90 of 2.5 h was 22.1/d and the low rate of death, based on a T90 of 15 h was 3.7/d. These values are for death of standing stock fecal coliforms per day, whereas bacteria associated with fresh sewage probably have faster death rates.

A decay rate constant for Hampton Harbor conditions at the marina can be chosen based on the above review of literature values. An estimate of decay constants between 3/d and 20/d seems reasonable, with a compromise, defendable decay rate, of 10/d, or T90 of 5.5 h. This estimate includes consideration of the following assumption:

-bacteria are associated with freshly discharged sewage;
-the bacteria used for the assessment are fecal coliforms;
-discharges occur during daytime when water T $\geq$ 10°C;
-receiving water is clear/non-turbid;
-receiving water is near ocean salinity (~35ppt) and low in organic matter;
-effluent medium has no influence on bacterial interaction in water column;
-discharged bacteria remain in water column;
-effluent and bacteria remain in shallow water, <~5 m.

RESULTS

1. Shoreline Survey

Results of the shoreline survey are detailed in Appendix 1. The surveyors found several areas of seepage from suspected malfunctioning septic systems, and several residences with visible pipes that may or may not have been gray water pipes. Though most samples of seep water had very low fecal coliform concentrations, a seep sample collected from a property on the south side of River Street had a fecal coliform concentration of ≈ 200,000 FC/100 ml (Table 1, APPENDIX I). This contamination would be transported via the network of tidal creeks through the marsh to the Blackwater River, and potentially impact the Seabrook clamflats during ebb tide. Samples taken from Seabrook Harbor near the Yankee Fisherman's Coop and immediately north of River Street had very low fecal coliform concentrations (Table 1, APPENDIX I).

2. Dilution dispersion modeling

Input Data

Based on the information obtained from review of mooring permit data, and discussions with the Port Authority Director and the Seabrook Harbormaster, it was determined that there are sixty five mooring permits issued for Seabrook Harbor. No live-aboard vessels are moored or docked in Seabrook Harbor. Vessels are moored more or less in single file running north to south past the coop pier, becoming more dense and clustered immediately south of the pier. Approximately 50% of the moorings are issued to pleasure craft in the 15'-26' LOA. These vessels, in addition to the Eastman charter fishing fleet, occupy the harbor seasonally (May through September). The remaining moorings are occupied by commercial fishing vessels which consist of small draggers, gillnetters and lobster boats, most of which are < 50' LOA. From mid-October through mid-May, approximately 35 commercial fishing vessels remain moored in Seabrook Harbor, as the pleasure craft and charter vessels are hauled out for the season. The commercial vessels are for the most part, day fishing boats that leave the harbor between 3-4 AM, fish the nearshore (generally <10 miles from shore) waters of the Gulf of Maine and return to unload their catch at the Cooperative in the early afternoon. For the purpose of both the CORMIX model and the slug discharge evaluation, it was assumed that each of the 35 vessels discharged wastes from one person over a six hour period.

The moorings begin approximately 100 meters north of the Yankee Fisherman's Cooperative and extends southward past the Coop pier and bulkhead (≈ 100 m wide) for approximately 300 meters southward to the terminus of the harbor channel at the Seabrook town pier and launch ramp and the Eastman Fishing Fleet pier and docks on River Street. The estimated total length of the mooring area is 500 m. At the northern end of the mooring area, the channel is 61 m wide, increasing to 77 m in width at the center of the Coop pier. South of the pier, the channel width increases to 101 m. Based on channel width and mooring density, an average width of 96 m and an average length of 300 m were used in the CORMIX model and slug discharge evaluation and assuming that vessels are moored in approximately mid-channel, the distance to the clamflat was estimated to be 48 m (Fig. 1).

The depth throughout the channel is approximately 3 m at MLW (Figs 2 and 3). The tidal prism in the harbor is 2.6 m, nearly doubling the harbor volume at MHW. Flood tide water will begin to flow over the clamflat when water level has risen approximately 0.61 m , or approximately 2.0 hrs. past the time of MLW. At hour 2.0, the average current velocity in the harbor channel is approximately 0.3 m/sec flowing due south (NH DPHS 1994). Lateral velocity of incoming water over the clamflat, perpendicular to the direction of the flood waters in the channel was estimated at 0.10 cm/sec. The initial run of the CORMIX model and the slug discharge evaluation used a longitudinal velocity of 0.10 and an equal lateral velocity (Appendix II). In order to more accurately simulate hydrographic conditions at the time that flood tide water contacts the clamflats, a subsequent run of CORMIX and the slug discharge evaluation used 0.30 m/sec longitudinal velocity and 0.10 m/sec for a lateral velocity and a decay coefficient of 10/day (Appendix III).

Results of the initial run of CORMIX are detailed in Appendix II A. Results of the run indicated that the concentration of the plume at the time of its intersection with the clamflat is 17.2 CFU/100 ml, which exceeds the allowable limit of 14 FC/100ml (Appendix II (page 2)). When the slug injection evaluation (Appendix II B) was run using the initial parameters and no decay coefficient, the concentration of the plume at the time of intersection with the clamflat was 30.0 CFU/100ml (Appendix II (page 3).

Subsequent runs of the CORMIX model and the slug discharge evaluation used a the decay coefficient described in the Methods section of this report, a longitudinal velocity of 0.30 m/sec, and a lateral velocity of 0.10 m/sec. Using these input data, CORMIX estimated that the concentration of the plume is 0.0176 FC/100 ml (Appendix III (pg A-2)) while the slug injection evaluation estimated that the plume concentration is 13 FC/100 ml when it intersects the clamflat. Both estimates are below the regulatory limit of 14 FC/100 ml.

DISCUSSION

Based on the findings of the shoreline survey update for the Seabrook Harbor area, it appears that residences adjacent to the harbor area should continue to be considered potential pollution sources which may impact the sanitary quality of the growing waters. The residences of concern are located on Cross Beach Road and the south side of River Street, adjacent to the marsh that connects with the Blackwater River via a network of small tidal creeks. Impact to the water in the river was not observed, however, the presence of contaminated seep water adjacent to the marsh was confirmed. Several Cross Beach residences on stilts had what appeared to be discharge pipes coming out of the bottom of the houses directed toward the ground. Though no discharge was observed, the presence of these pipes is suspect.

Though routine monitoring indicates that the water quality is for the most part within the regulatory limit of 14 FC/100 ml, water samples taken near these residences indicate that contaminated effluent may intermittently affect the growing area. It is recommended that the Seabrook clamflat should remain closed until these residences are connected to the Seabrook Municipal Sewage Treatment Plant.

Guidance for control of areas used as a marina provided by Part I of the NSSP manual (NSSP 1993) requires that water circulation, water volume and mixing rate, as well as consideration of the number and types of vessels in an area be evaluated when considering the closure zone adjacent to a marina. Based on the analysis conducted for this report, the vessels that are present in the harbor from mid-October to mid-May do not pose a risk of contamination of the Seabrook clamflats at a level that would require closing the area. If the recreational vessels that occupy the moorings and docks (including the Eastman fleet) at the peak of the boating season (mid-May through September) are included in the analysis, there would be potential risk of contamination of the growing area from illegal discharge of wastes. It is recommended therefore that the flats remain closed from mid-May through September, or until the pleasure craft and charter vessels are removed for the season.

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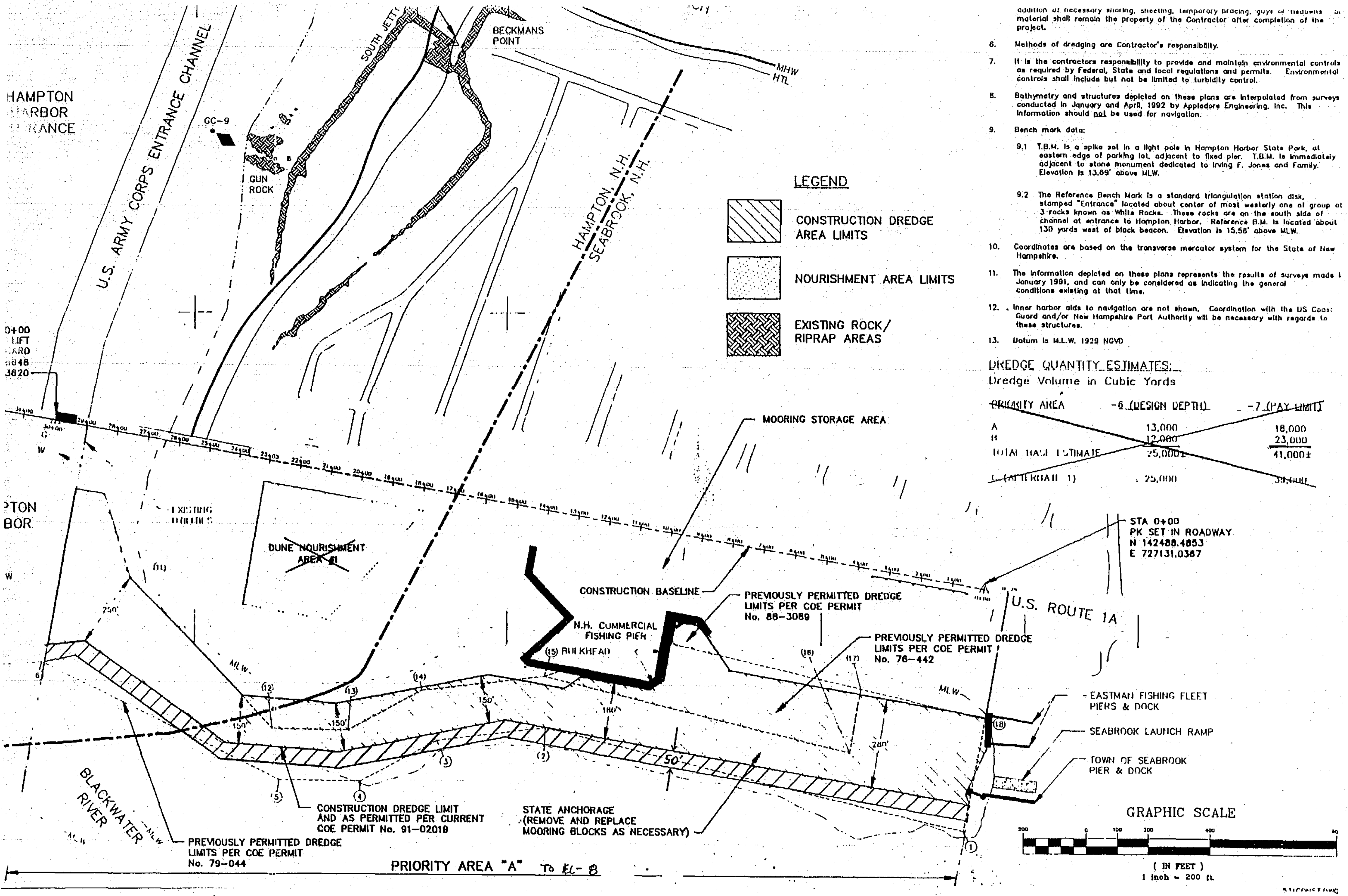

Figure 1. Schematic of Seabrook Harbor showing shape and dimensions of the harbor

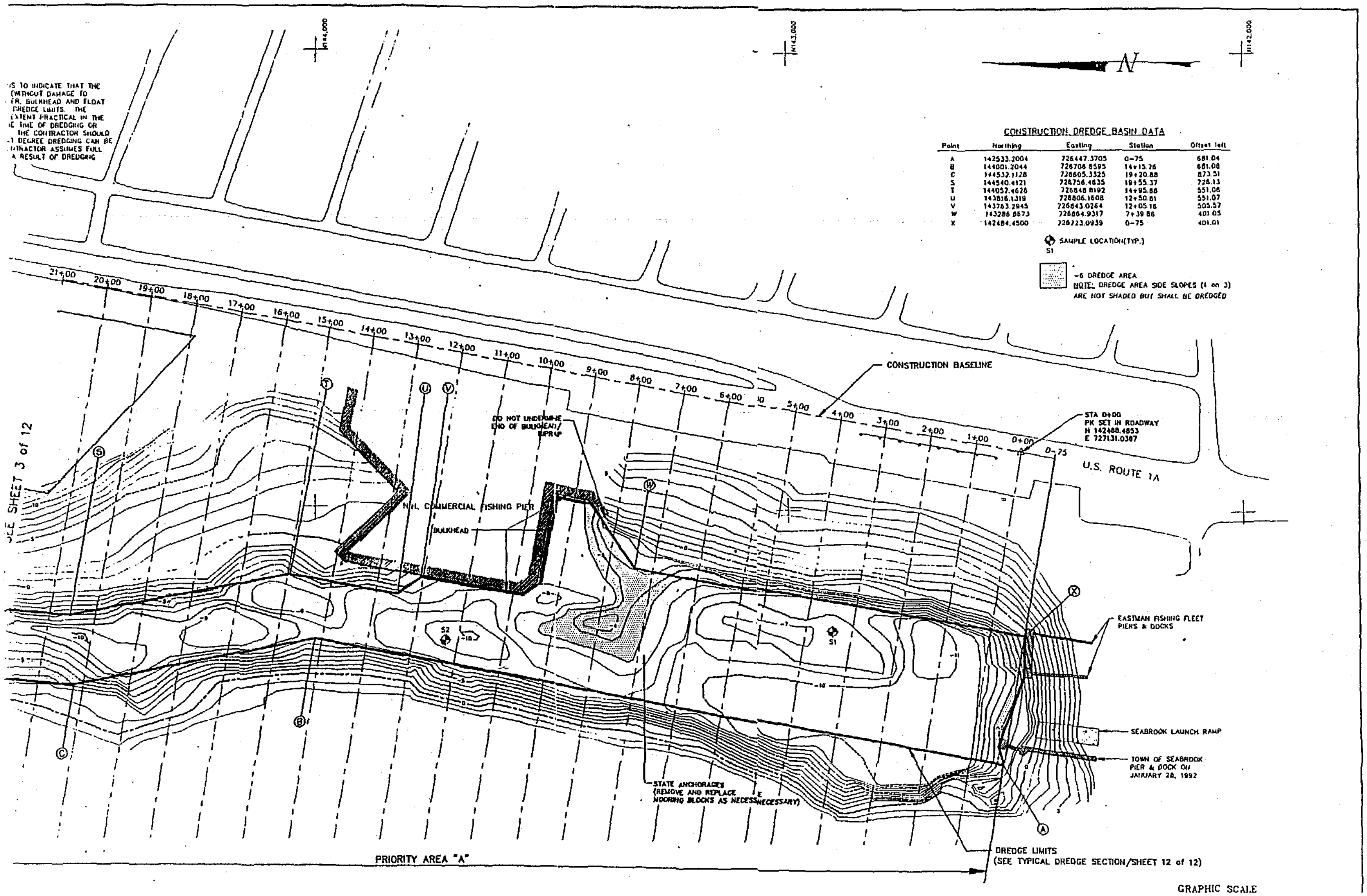

Figure 2. Schematic of Seabrook Harbor showing depth contours and dredge areas

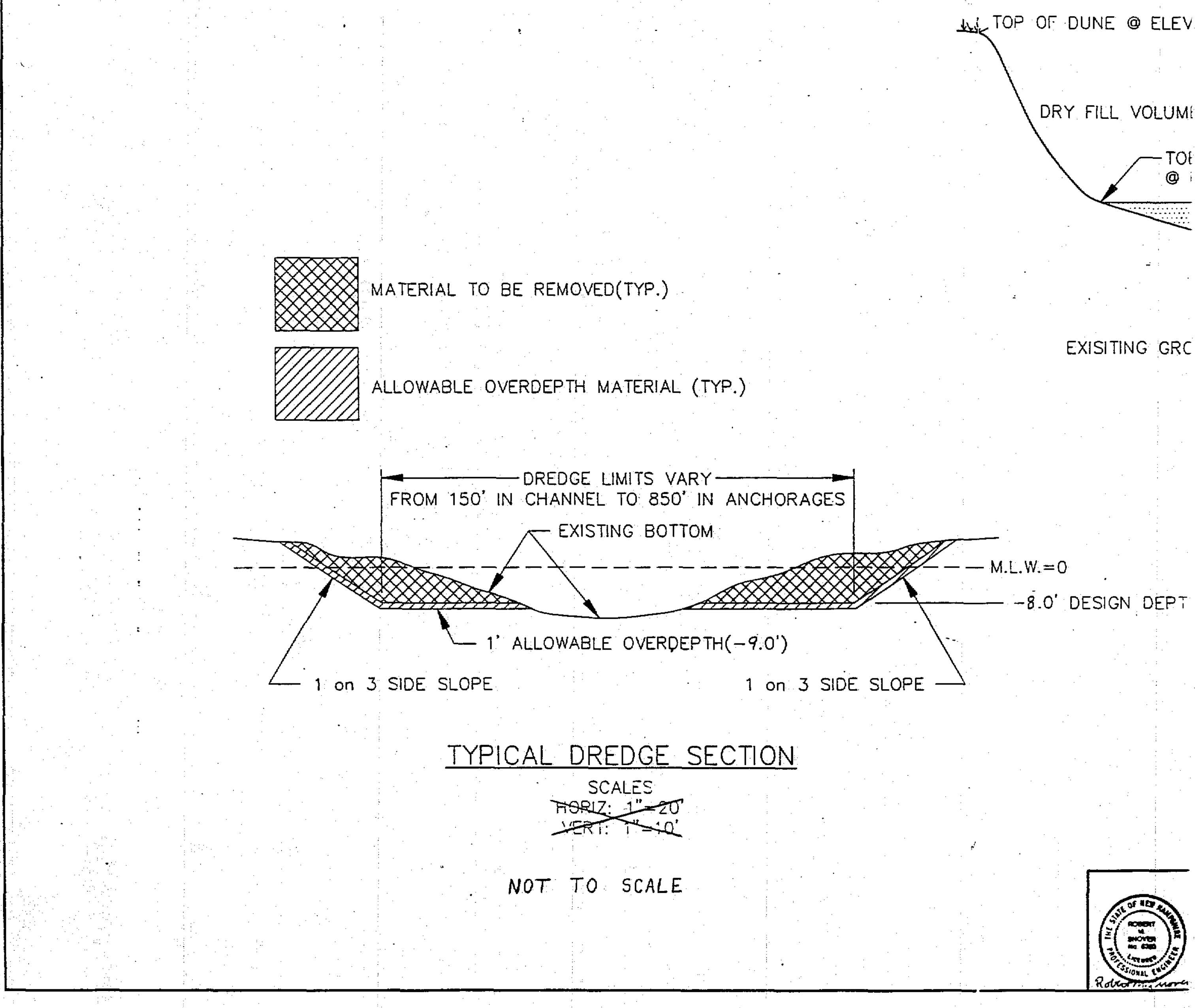

Figure 3. Cross section of the Seabrook Harbor channel showing depth and slope of dredged area

APPENDIX I

Seabrook Harbor Shoreline Survey

Seabrook Harbor Shoreline Survey
Field Report Summary

Friday, 6/2/95

The surveyors present were Andrea Tomlinson and Deborah Lamson. After crossing the Route 1A bridge into Seabrook, we parked at the public beach parking lot (first lot on the right) to inspect the Yankee Fisherman's Coop and the surrounding shoreline. The Seabrook Public Works crew was pumping groundwater out at the roadside and draining it into the harbor. This was done the previous week throughout the area in preparation for the new sewer lines which are being installed in the Seabrook. Groundwater from the canvas pipes which were draining into the harbor at the rock wall next to the coop were sampled. Results of sample analyses are presented in Table 1.

At River Street, we began the shoreline inspection along the harbor at Eastman's. At the Hopkinson/Pike/Camacho properties there is a large granite retaining wall on the shore. From under the wall seepage was draining directly into the harbor over an area of >60 feet in length. Two samples were taken at each end of the seepage along with two samples of the harbor water just offshore from the seepage site.

On the south side of River Street facing the marsh, other suspected pollution sources were found. At the Welch residence, a 3" PVC pipe was discharging gray water into the abutting marshland. A water sample of the discharge was obtained. Next to this pipe, coming from under the wooden backyard fence was a small pool of dark-colored, foul smelling water. Next to the Welch residence were the Knowles. A sample was taken from a stagnant tidal pool which appeared to originate from the backyard via a drainage stream underneath the backyard fence. Further down the road, going back toward Rt. 1A and Eastman's, we discovered a black-colored stream of water coming from underneath a wood pile about four feet in height between the Gynan and Kent residence. The origin appeared to be coming from the Kent property, as there was evidence (dirt heaped up in a straight line) of an underground pipe which led in the direction of their home. A sample of this seepage was obtained.

From River Street, we went to Cross Beach Road where we saw that all twenty trailer and homes had newly installed manholes for the new sewer lines. At the end of the road, we found numerous wooden houses on stilts with black or white (PVC) piping coming from the center of the houses and draining onto the ground directly underneath the houses. These pipes were possibly gray water pipes, though no active discharges were observed. All twenty trailers/homes are situated on hydric marshland/dunes and it is suspected that most if not all have unsuitable septic and graywater treatment. Small livestock were observed at one of the residences on the south side of Cross Beach Road. Among the animals visible were three goats and seven ducks.

Table 1. Seabrook Harbor Shoreline Survey
River St. and Cross Beach Rd., Seabrook, NH: Fecal coliform levels.

House #	Location	Description	Owner	Map #	FC/100ml
14	14 River St.	Seepage-1	Hopkinson	SB 1	<5
14	14 River St.	Seepage-2	Hopkinson	SB 1	<5
30	30 River St.	Gray water pipe	Welch	SB 1	Bkgd *
31	31 River St.	Septic seepage	Knowles	SB 1	60
36/37	Between 36 & 37 River St.	Septic seepage	Gynan/Kent	SB 1	~200000
NA	Harbor at River St.	Harbor sample	NA	SB 1	0
NA	Rocks at Yankee Coop	Groundwater	Town of Seabrook	SB 1	1

* Bkgd- Background growth interference extensive; couldn't read

APPENDIX II

Initial Runs of CORMIX Model and Slug Injection Evaluation

Diffusion Study on

Contamination of the Seabrook Clamflat

in Hampton Harbor

Holly E. Clark

Report Prepared for:

Dr. Richard Langan
June 20, 1995

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June 20, 1995

Dr. Richard Langan
Jackson Estuarine Laboratory
Durham, NH 03824

Subject: Diffusion Study on Contamination of the Seabrook Clamflat in Hampton Harbor

Dear Dr. Langan:

The southeastern region of Hampton Harbor, located in Seabrook, NH, was evaluated using CORMIX, a diffuser modeling program. The diffusion of discharges from moored vessels in the channel was investigated. The purpose was to estimate the concentrations of fecal coliform that would appear in the clamflat adjacent to the channel.

The result of the study shows that the high concentration associated with the vessel discharge would not be reduced to safe levels before it reaches the clamflat. The CORMIX modeling assumed that the discharge would be released over a period of 6 hours. The result of the diffuser model shows that the fecal coliform count remains at 17.2 CFU/100mL as it flows over the clamflat. This is above the acceptable limit of 14 CFU/100mL.

The CORMIX model shows the result of the release from the vessel as if it were mixed slowly with the tidewater. The release from a vessel would occur as a slug rather than a continuous release rationed out over time. Therefore, the CORMIX model is not appropriate for this application. Through the use of an advection-dispersion model, the dilution of the discharge from a vessel is found to be somewhat less. The resulting concentration to reach the mudflat could be approximately 30 CFU/100mL.

Due to the high concentration of $2x10^9$ CFU in a 12L vessel release, it is not likely that adequate mixing and dispersion could occur within the channel reaches and prevent contamination of the clamflat. A tracer study using a slug injection method at a mooring in the harbor could be used to demonstrate the spreading and movement of the vessel discharge into the area of interest. It is likely that the tracer study would support the conclusion that the contamination would occur.

The details of the study are included in the report. Thank you for considering me for this study. Please feel free to call at 862-3623 if you have any questions or comments.

Sincerely,

Holly E. Clark

Holly E. Clark

I. Introduction:

Description of Area

This study concerns the southeastern region of Hampton Harbor that is located in Seabrook, NH. A channel along the eastern shore of the harbor is approximately 96m (315 ft) wide by 500m (1640 ft) long by 3m (10 ft)deep at low tide. A mudflat flanks the west bank of the channel. During the flood of the tide cycle, the channel fills with water, overflows across the mudflat, and fills the harbor. During the ebb, the mudflat drains to the West and the channel drains to the North. There are moorings located along the centerline of the channel that are approximately 48m (158 ft) east of the mudflat.

Assumptions for Modeling

The purpose of this study is to investigate the possibility that the clam beds in the mudflats (clamflats) will be contaminated by discharges from the moored boats. This study is based on modeling the diffusion of the discharge into the flow of the water through this area. The program used to model this situation is not designed for this application. Adjustments were made to the "actual" situation to fit the model parameters. The assumptions used in the modeling are as follows:

- There are 35 equally spaced vessels moored 300m (984 ft) along the centerline of the channel;
- Each vessel discharges once over a 6 hr period;
- Each discharge is 12 L (3.2gal) with a fecal coliform count of 2×10^9 CFU per discharge;
- The effluent is assumed to be dispensed continuously for 6 hrs;
- Due to the short duration, no decay coefficient is used;
- The density of the effluent is 1010.15 kg/m^3;
- The channel is 3m(9.8 ft) deep relative to the mudflat;
- The tide flows south in the channel for 2 hrs, then flows west over the mudflat for 4 hrs;
- The velocity in the channel and over the mudflat is 0.1m/s (0.2 knots);
- The effluent over the mudflat is discharged from 35 ports;
- The initial concentration of the effluent over the mudflat is determined from the plume in the channel.

II. Modeling Studies:

CORMIX Modeling

The CORMIX modeling program models the effluent discharged from a diffuser in a stream. It is used to determine the concentration gradient in the plume. In this case a multiport diffuser placed along the centerline of the channel simulates the moored vessels. The discharge of the vessels was converted to a flow rate over a half tide cycle of 6 hours. The assumption is that if all the vessels discharge in that period of time, the worst case will be investigated.

The CORMIX model was run in two stages. The first stage assumed that the initial vessel discharge was occurring as the channel was filling. A mass balance equation was used to determine the initial concentration in the effluent if 0.1 m/s (0.33 ft/s) velocity and 0.051m (2 in) diameter ports were used. The resulting concentration was 5426700 CFU/100mL (Appendix A). The first stage determined that the discharge from the diffuser is fully mixed vertically and laterally in the channel in approximately 2 hours. The concentration of the mixture is 5380 CFU/100mL as shown in the CORMIX output (Appendix A). The total colony forming units (CFU) discharged by the 35 vessels was used in a mass balance equation to determine the flow rate at the new concentration to be discharged over the clamflat in a 4 hour period. The resulting flow rate of 0.1m^3/s (3.5cfs) was used to determine the size of the discharge ports. The diameter of the ports at 0.18m (7.1 in) maintained the 0.1 m/s (0.33 ft/s) discharge velocity (Appendix A).

The second stage of the CORMIX model was run for a 500m (1640 ft) wide stream that was 1m (3.3 ft) deep. The diffuser had 35 ports and was centered in the channel perpendicular to the westerly flow of the incoming tide. The model predicted that the concentration would remain at 17.2 CFU/100mL as it flowed over the clamflat (Appendix A). A second model with the clamflat "stream" at 1.5m (4.9 ft) deep found the concentration stabilizing at 11.9 CFU/100mL

(Appendix A). Although the depth over the clamflat ranges from 0 to 2.5m (0 to 8.2 ft), an average constant depth of either the 1m (3.3 ft) or 1.5m (4.9 ft) was used to run the model.

There are many differences between the model and the actual situation. The CORMIX model assumes steady flow with a continuous discharge in a small stream. The tide is flowing into the channel so the depth is constantly increasing which is unsteady flow. Each vessel is "actually" discharging an entire 12 L (3.2 gal) slug into the channel. The injections from 35 vessels are intermittent. The channel is similar to a stream as it fills but the flow "backs up" rather than flowing downstream. The flow of the water changes direction as the water rises enough to flow over the mudflat. The vessels are discharging near the surface and the model assumes a diffuser is positioned near the bottom.

The model simulation is less conservative than the actual conditions because of these differences. The most important disparity is the adjustment from intermittent injections to a continuous discharge. The model is seeing a discharge that is already spread out over time. It is assumed that the continuous injection would show a continuous plume that is similar in dimensions to a single moving plume from a slug injection. From there, the second stage of modeling was performed.

<u>Advection-Dispersion Evaluation of a Slug Injection</u>

A second way of looking at this situation is to use an advection-dispersion equation for a slug injection. The McQuivey and Keefer equation for the dispersion coefficient was used. The assumptions for this modeling are:

- Bed slope is 0.001;
- Stream is 96m (315 ft) wide by 3m (9.8 ft) deep;
- Velocity of the seawater is constant at 0.1 m/s (0.2 knots).

The dispersion coefficient was determined to be 17.4 (Appendix B). The discharge from one vessel was assumed to be fully mixed at 360m (1181 ft) downstream. The concentration was determined to be 1.93 CFU/100mL when fully mixed in a 96m (315 ft) wide by 3m (9.8 ft) deep by 360m (1181 ft) long section of the channel. Using the dispersion coefficient in an advection-dispersion equation resulted in a peak concentration of 1.4 CFU/100mL at 360m (1181 ft) downstream. The dispersion coefficient appears to be appropriate. This method was applied to the discharge from a vessel flowing directly at the mudflat during a tidal flow velocity of 0.1m/s (0.2 knots). The result shows that a peak concentration of approximately 30 CFU/100mL will reach the mudflat (Appendix B). This is above the acceptable limit of 14 CFU/100mL.

Mass Balance

Another way of viewing the situation is based on mass balances. The discharge from one vessel is assumed to be fully mixed in a hypothetical cylindrical volume centered on the vessel. The concentration throughout this cylinder is 14 CFU/100mL. Using a mass balance equation, when the channel is 3m (9.8 ft) deep the radius of the cylinder is 39m (128 ft). This shows that if the water is stagnant and mixing is complete (somehow), the discharge from a vessel could be diffused prior to reaching the mudflats. Adding in a velocity for the tidal water of 0.1m/s (0.2 knots) results in the fully mixed hypothetical cylinder reaching the mudflat in 1.5 minutes. The effluent does not mix in this manner but it does illustrate the likelihood that the fecal coliform concentration would not be reduced sufficiently before reaching the mudflats.

III. Conclusion:

Although the CORMIX method used is not fully applicable to the situation, the predictions tend to show that the clamflats could see concentrations above the maximum level of 14 CFU/mL. The use of the advection-dispersion equation on a single vessel discharge also shows that the clamflats could be contaminated by the discharge.

The velocity of the water in the channel moves the effluent quickly over the relatively short distance from the moorings to the clamflat. The high concentration of the effluent requires a large volume of water to reduce it to 14 CFU/100mL. If the assumptions concerning the effluent concentration and channel characteristics are correct, it is apparent that a single vessel discharge into the channel might not mix adequately with the ambient water to achieve 14 CFU/100mL within 48m (158 ft) of the mooring.

A tracer study using a slug injection method into the harbor could be used to demonstrate the advection and dispersion of the vessel discharge into the area of interest. It is likely that the tracer study would support the conclusion that there is inadequate mixing of the vessel discharge.

Appendix A

The Department of Civil Engineering College of Engineering and Physical Sciences The University of New Hampshire Kingsbury Hall 33 College Road Durham, New Hampshire 03824-3591	Project/Problem Set: Cormix Modeling Detail/Problem: Stage 1 - Mass Balance Class: ______ Prof: ______	Sheet: A1 of 25 Calc. by: Holly Clark Date: 6/17/95 Chck. by: ______ Date: ______	

Given: 35 vessels
Discharge per vessel = 12 L
One discharge per vessel over 6 hrs.
Initial concentration is 2×10^9 CFU/12 L

Find: Concentration of effluent if it is discharged through 35 ports of 0.051 m diameter each at a velocity of 0.1 m/s.

① finding ~~total~~ discharge of vessels, Q_T

$$Q_T = \frac{(35 \text{ vessels})(12 \text{ L})(0.001 \text{ m}^3/\text{L})}{6 \text{ hr } (3600 \text{ sec/hr})} = 1.944 \times 10^{-5} \text{ m}^3/\text{s}$$

② finding area of 35 ports, A

$$A = \frac{(0.051)^2 \pi}{4}(35) = 0.0715 \text{ m}^2$$

③ finding discharge from multiport diffuser, Q_D

$$Q_D = VA = (0.1 \text{ m/s})(0.0715 \text{ m}^2) = 0.00715 \text{ m}^3/\text{s}$$

④ finding concentration of discharge from multiport diffuser, C_D

$$\frac{Q_T C_i}{Q_D} = C_D = \frac{(1.94 \times 10^{-5} \text{ m}^3/\text{s})(2 \times 10^9 \text{ CFU/100 mL})}{0.00715 \text{ m}^3/\text{s}} = 5426700 \text{ CFU/100mL}$$

Stage 1: Assume effluent is discharged from a multiport diffuser with 35 ports. The ports alternate on the diffuser pipe. Port diameter is 0.051 m. Spacing of the ports is 8.8 m on a 300 m long diffuser. The pipe is positioned along the centerline of the channel in a North-South direction.

This effluent flow rate assumes that all the vessels are discharging slowly for 6 hrs simultaneously.

A2

CHECKLIST FOR DATA PREPARATION

CORMIX -- CORNELL MIXING ZONE EXPERT SYSTEM -- CORMIX

SITE Name: Seabrook Harbor Mudflat — Date: 6/17
Design CASE: Multiport discharge into channel — Prepared by: H2Clal
DOS FILE NAME: Stagelma (w/o extension)

AMBIENT DATA:

Water body depth	3 m	Water body is	bounded/unbounded
Depth at discharge	3 m	If bounded: Width	96 m
		Appearance	1/2/3
Ambient flowrate	___ m³/s or:	Ambient velocity	0.1 m/s
Manning's n	0.014 or:	Darcy-Weisbach f	(0.010)
Wind speed	2 m/s		

Density data: UNITS: Density...kg/m³ / Temperature...°C

Water body is	fresh/salt water	If fresh: Specify as	density/temp. values
If uniform:		Average density/temp.	1010.5
If stratified:		Density/temp. at surface	
Stratification type	A/B/C	Density/temp. at bottom	
If B/C: Pycnocline height	___ m	If C: Density/temp. jump	

DISCHARGE DATA: Specify **geometry** for CORMIX1 or 2 or 3

SUBMERGED SINGLE PORT DISCHARGE -- CORMIX1

Nearest bank is on	left/right	Distance to nearest bank	___ m
Vertical angle THETA	___ °	Horizontal angle SIGMA	___ °
Port diameter	___ m or:	Port area	___ m²
Port height	___ m		

SUBMERGED MULTIPORT DIFFUSER DISCHARGE -- CORMIX2

Nearest bank is on	left/right	Distance to one endpoint	48 m
Diffuser length	300 m	to other endpoint	48 m
Total number of openings	35		
Port diameter	0.051 m	with contraction ratio	K = 1
Diffuser arrangement/type	unidirectional / staged / alternating or vertical		(B), (A)
Alignment angle GAMMA	0 °	Horizontal angle SIGMA	___ °
Vertical angle THETA	90 °	Relative orientation BETA	___ °
Port height	0.99 m	(A) = holes (single ports)	

BUOYANT SURFACE DISCHARGE -- CORMIX3

Discharge located on	left/right bank	Configuration	flush/protruding/co-flowing
Horizontal angle SIGMA	___ °	If protruding: Dist. frm bank	___ m
Depth at discharge	___ m	Bottom slope	___ °
If rectangular Width	___ m or:	If circular Diameter	___ m
discharge channel: Depth	___ m	pipe: Bottom invert depth	___ m

Effluent: Flow rate	0.00714 m³/s or:	Effluent velocity	(0.1) m/s
Effluent density	1010.15 kg/m³ or:	Effluent temperature	___ °C
Heated discharge?	yes/no	If yes: Heat loss coefficient	___ W/m²,°C
Concentration units	CFU-Per-100mL	Effluent concentration	5426700
Conservative substance?	yes/no	If no: Decay coefficient	___ /day

MIXING ZONE DATA:

Is effluent toxic?	yes/no	If yes: CMC value	14
		CCC value	14
WQ stand./conventional poll.?	yes/no	If yes: value of standard	
Any mixing zone specified?	yes/no	If yes: distance	___ m
		or width	___ % or m
Region of interest	1000 m	or area	___ % or m²

```
CORMIX2 PREDICTION FILE:
2222222222222222222222222222222222222222222222222222222222222222222222
                    CORNELL MIXING ZONE EXPERT SYSTEM
Subsystem CORMIX2:                                    Subsystem version:
 Submerged Multiport Diffuser Discharges   CMX2 v.2.10          May 1993
----------------------------------------------------------------------
----------------------------------------------------------------------
CASE DESCRIPTION
 Site name/label:          Seabrook^Harbor^Mudflat
 Design case:              Multiport^discharge^at^300m^
 FILE NAME:                cormix\sim\stage1ma.cx2
 Time of Fortran run:      06/17/95--10:33:01

ENVIRONMENT PARAMETERS (metric units)
 Bounded section
 BS     =     96.00  AS     =     288.00  QA     =      28.80
 HA     =      3.00  HD     =       3.00
 UA     =      .100  F      =       .011  USTAR = .3651E-02
 UW     =     2.000  UWSTAR= .2198E-02
 Uniform density environment
 STRCND=  U          RHOAM = 1010.5000

DIFFUSER DISCHARGE PARAMETERS (metric units)
 DITYPE=alternating parallel
 BETYPE=alternating without fanning
 BANK   =  LEFT      DISTB =        .00  YB1    =      48.00  YB2    =      48.00
 LD     =    300.00  NOPEN =   35        SPAC   =       8.82
 D0     =      .051  A0     =       .002  H0     =        .99
 GAMMA =        .00  THETA =      90.00
 SIGMA =        .00  BETA   =     90.00
 U0     =      .100  Q0     =       .007         = .7140E-02
 RHO0   = 1010.1500  DRHO0 = .3500E+00  GP0    = .3396E-02
 C0     = .5427E+07  CUNITS=  CFU-per-100mL
 IPOLL =  1          KS     = .0000E+00  KD     = .0000E+00

DIFFUSER PARAMETERS WITH IMAGE EFFECTS (metric units)
 The bank/shore proximity effect is accounted for by the following flow
 variables and definitions of length scales and parameters.
 LD     =    300.00  Q0     =       .014 (Q0     = .1428E-01)

FLUX VARIABLES - PER UNIT DIFFUSER LENGTH (metric units)
 q0     = .9500E-04  m0     = .2370E-05  j0     = .8067E-07  SIGNJ0=      1.0
 Associated 2-d length scales (meters)
 lQ=B   =      .001  lM     =        .13  lm     =        .00
 lmp    =  99999.00  lbp    =   99999.00  la     =   99999.00

FLUX VARIABLES - ENTIRE DIFFUSER (metric units)
 Q0     = .1428E-01  M0     = .7111E-03  J0     = .2420E-04
 Associated 3-d length scales (meters)
 LQ     =       .41  LM     =        .89  Lm     =        .35  Lb     =        .05
                                          Lmp    =   99999.00  Lbp    =   99999.00

NON-DIMENSIONAL PARAMETERS
 FR0    =    110.99  FRD0   =       7.58  R      =        .99
 (slot)               (port/nozzle)

FLOW CLASSIFICATION
 222222222222222222222222222222222222222222
 2  Flow class (CORMIX2)        =     MU1H   2
 2  Applicable layer depth HS =      3.00   2
```

```
2222222222222222222222222222222222222222222

MIXING ZONE / TOXIC DILUTION / REGION OF INTEREST PARAMETERS
 C0     = .5427E+07  CUNITS=  CFU-per-100mL
 NTOX   =  1         CMC    = .1400E+02  CCC    =  CSTD
 NSTD   =  1         CSTD   = .1400E+02
 REGMZ  =  0
 XINT   =   1000.00  XMAX   =   1000.00

X-Y-Z COORDINATE SYSTEM:
  because of bank/shore proximity, the ORIGIN is located directly
   at the LEFT  bank/shore.
  the bank/shore acts as a plane of symmetry for   the predicted
  plume geometry.
    X-axis points downstream, Y-axis points to left, Z-axis points upward.
NSTEP =  5 display intervals per module
---------------------------------------------------------------------------
---------------------------------------------------------------------------
BEGIN MOD201: DIFFUSER DISCHARGE MODULE

 Profile definitions:
   BV = Gaussian 1/e (37%) half-width, in vertical plane normal to trajectory
   BH = top-hat half-width, in horizontal plane normal to trajectory
   S  = hydrodynamic centerline dilution
   C  = centerline concentration (includes reaction effects, if any)

      X         Y        Z        S       C         BV        BH
     .00       .00      .99      1.0  .543E+07      .00    150.00

END OF MOD201: DIFFUSER DISCHARGE MODULE
---------------------------------------------------------------------------
---------------------------------------------------------------------------
BEGIN MOD211: WEAKLY DEFLECTED PLANE JET IN CROSSFLOW

 CROSSFLOWING DISCHARGE

 This flow region is INSIGNIFICANT in spatial extent and will be by-passed.

END OF MOD211: WEAKLY DEFLECTED PLANE JET IN CROSSFLOW
---------------------------------------------------------------------------
---------------------------------------------------------------------------
BEGIN MOD222: STRONGLY DEFLECTED PLANE PLUME IN CROSSFLOW

 Profile definitions:
   BV = Gaussian 1/e (37%) half-width, in vertical plane normal to trajectory
   BH = top-hat half-width, in horizontal plane normal to trajectory
   S  = hydrodynamic centerline dilution
   C  = centerline concentration (includes reaction effects, if any)

      X         Y        Z        S       C         BV        BH
     .00       .00      .99      1.0  .543E+07      .00    150.00
   94.61       .00     1.29    567.8  .956E+04      .18    150.18
  189.22       .00     1.59   1134.5  .478E+04      .36    150.36
  283.83       .00     1.89   1701.3  .319E+04      .54    150.54
  378.43       .00     2.20   2268.0  .239E+04      .72    150.72
  473.04       .00     2.50   2834.8  .191E+04      .90    150.90
 Cumulative travel time =        4730. sec

END OF MOD222: STRONGLY DEFLECTED PLANE PLUME IN CROSSFLOW
---------------------------------------------------------------------------
```

BEGIN MOD243: DENSITY CURRENT DEVELOPING ALONG PARALLEL DIFFUSER LINE

The plume for this parallel diffuser interacts with the surface/pycnocline or the bottom, and a DENSITY CURRENT forms.
Note: The starting x-coordinate of the developing plume will be shifted upstream.

Profile definitions:
BV = top-hat thickness, measured vertically
BH = top-hat half-width, measured horizontally in y-direction
ZU = upper plume boundary (Z-coordinate)
ZL = lower plume boundary (Z-coordinate)
S = hydrodynamic average (bulk) dilution
C = average (bulk) concentration (includes reaction effects, if any)

X	Y	Z	S	C	BV	BH
323.04	.00	3.00	2834.8	.191E+04	.90	.90
383.04	.00	3.00	4009.0	.135E+04	3.00	.96
443.04	.00	3.00	4009.0	.135E+04	3.00	1.01
503.04	.00	3.00	4009.0	.135E+04	3.00	1.07
563.04	.00	3.00	4009.0	.135E+04	3.00	1.13
623.04	.00	3.00	4009.0	.135E+04	3.00	1.19

Cumulative travel time = 7730. sec

END OF MOD243: DENSITY CURRENT DEVELOPING ALONG PARALLEL DIFFUSER LINE

** End of NEAR-FIELD REGION (NFR) **

Recall that the plume is symmetric to the bank/shore on which the centerline (X-axis) is located.

The LIMITING DILUTION (given by ambient flow/discharge ratio) is: 1009.4
This value is below the computed dilution of 4009.0 at the end of the NFR.
Mixing for this discharge configuration is constrained by the ambient flow.

The previous module predictions are unreliable since the limiting dilution cannot be exceeded for this diffuser in deep unstratified layer.

A subsequent module (MOD281) will predict the properties of the cross-sectionally fully mixed plume with limiting dilution and will compute a POSSIBLE UPSTREAM WEDGE INTRUSION.

BEGIN MOD281: MIXED PLUME/BOUNDED CHANNEL/POSSIBLE UPSTREAM WEDGE INTRUSION

The DOWNSTREAM flow field for this unstable shallow water discharge is VERTICALLY FULLY MIXED.
The mixing is controlled by the limiting dilution = 1009.4 ⇐

Channel DENSIMETRIC FROUDE NUMBER (FCHAN) for this mixed flow = 31.47

No upstream wedge intrusion takes place since FCHAN exceeds the critical value of 0.7.

X	Y	Z	S	C	BV	BH	ZU	ZL
623.04	.00	3.00	1009.4	.538E+04	3.00	96.00	3.00	.00

Cumulative travel time = 7730. sec = 2.15 hr

VERTICALLY AND LATERALLY FULLY MIXED over layer depth: END OF SIMULATION!

```
END OF MOD281: MIXED PLUME/BOUNDED CHANNEL/POSSIBLE UPSTREAM WEDGE INTRUSION
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
CORMIX2: Submerged Multiport Diffuser Discharges       End of Prediction File
22222222222222222222222222222222222222222222222222222222222222222222222222222
```

```
CORMIX SESSION REPORT:
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
                  CORMIX: CORNELL MIXING ZONE EXPERT SYSTEM
                      CORMIX v.2.10            May 1993
SITE NAME/LABEL:                  Seabrook Harbor Mudflat
  DESIGN CASE:                    Multiport discharge at 300m
  FILE NAME:                      stage1ma
Using subsystem CORMIX2:          Submerged Multiport Diffuser Discharges
  Start of session:               06/17/95--10:26:52
*******************************************************************************
SUMMARY OF INPUT DATA:
-------------------------------------------------------------------------------
AMBIENT PARAMETERS:
  Cross-section                            = bounded
  Width                           BS       =            96 m
  Channel regularity                       = 1
  Ambient flowrate                QA       =         28.80 m^3/s
  Average depth                   HA       =             3 m
  Depth at discharge              HD       =             3 m
  Ambient velocity                UA       =            .1 m/s
  Darcy-Weisbach friction factor  F        =        0.0106
    Calculated from Manning's n            =          .014
  Wind velocity                   UW       =             2 m/s
Stratification Type               STRCND   = U
  Surface density                 RHOAS    =        1010.5 kg/m^3
  Bottom density                  RHOAB    =        1010.5 kg/m^3
-------------------------------------------------------------------------------
DISCHARGE PARAMETERS:             Submerged Multiport Diffuser Discharge
  Diffuser type                   DITYPE   = alternating parallel
  Diffuser length                 LD       = 300 m
  Nearest bank                             = left
  Diffuser endpoints              YB1      =       48 m;    YB2 =       48 m
  Number of openings              NOPEN    =           35
  Spacing between risers/openings SPAC     =          8.82 m
  Port/Nozzle diameter            D0       =          .051 m
  Equivalent slot width           B0       =        0.0002 m
  Total area of openings          A0       =        0.0020 m^2
  Discharge velocity              U0       =          0.09 m/s
  Total discharge                 Q0       =        .00714 m^3/s
  Discharge port height           H0       =           .99 m
  Nozzle arrangement              BETYPE   = alternating without fanning
  Diffuser alignment angle        GAMMA    =             0 deg
  Vertical discharge angle        THETA    =          90.0 deg
  Horizontal discharge angle      SIGMA    =           0.0 deg
  Relative orientation angle      BETA     =          90.0 deg
  Discharge density               RHO0     =       1010.15 kg/m^3
  Density difference              DRHO     =        0.3500 kg/m^3
  Buoyant acceleration            GP0      =         .0034 m/s^2
  Discharge concentration         C0       =           5426700 CFU-per-100mL
  Surface heat exchange coeff.    KS       =             0 m/s
  Coefficient of decay            KD       =             0 /s
-------------------------------------------------------------------------------
FLUX VARIABLES PER UNIT DIFFUSER LENGTH:
  Discharge (volume flux)         q0       =      0.000095 m^2/s
  Momentum flux                   m0       =      0.000004 m^3/s^2
  Buoyancy flux                   j0       =             0 m^3/s^3
-------------------------------------------------------------------------------
DISCHARGE/ENVIRONMENT LENGTH SCALES :
  lq  =       0.00 m        lm  =       0.00 m        lM =       0.12 m
```

A8 .

```
  lm' =    99999.0 m          lb' =    99999.0 m          la =    99999.0 m
  (These refer to the actual discharge/environment length scales.)
-----------------------------------------------------------------------------
NON-DIMENSIONAL PARAMETERS:
  Slot Froude number                FR0     =     110.99
  Port/nozzle Froude number         FRD0    =       7.58
  Velocity ratio                    R       =       0.99
-----------------------------------------------------------------------------
MIXING ZONE / TOXIC DILUTION ZONE / AREA OF INTEREST PARAMETERS:
  Toxic discharge                           = yes
  CMC concentration                 CMC     =                 14 CFU-per-100mL
  CCC concentration                 CCC     =                 14 CFU-per-100mL
  Water quality standard                    = given by CCC value
  Regulatory mixing zone                    = no
  Region of interest                        =      1000.00 m downstream
*****************************************************************************
HYDRODYNAMIC CLASSIFICATION:
  *------------------------*
  | FLOW CLASS   =    MU1H |
  *------------------------*
  This flow configuration applies to a layer corresponding to the full water
  depth at the discharge site.
  Applicable layer depth = water depth =           3 m
*****************************************************************************
MIXING ZONE EVALUATION (hydrodynamic and regulatory summary):
-----------------------------------------------------------------------------
X-Y-Z Coordinate system:
  Origin is located at the bottom below the port center:
           0.0 m from the left bank/shore.
-----------------------------------------------------------------------------
NEAR-FIELD REGION (NFR) CONDITIONS :
Note: The NFR is the zone of strong initial mixing.  It has no regulatory
  implication.  However, this information may be useful for the discharge
  designer because the mixing in the NFR is usually sensitive to the
  discharge design conditions.
  Pollutant concentration at edge of NFR =       1353.6320 CFU-per-100mL
  Dilution at edge of NFR                =       4008.9  ← This dilution is not
  NFR Location:                        x =       623.04 m   possible as seen in
    (centerline coordinates)           y =          .00 m   the prediction file:
                                       z =         3.00 m   MAX DILUTION is 1009.4
  NFR plume dimensions:       half-width =         1.18 m
                               thickness =         3.00 m
-----------------------------------------------------------------------------
Buoyancy assessment:
  The effluent density is less than the surrounding ambient water
  density at the discharge level.
  Therefore, the effluent is POSITIVELY BUOYANT and will tend to rise towards
  the surface.
************************ TOXIC DILUTION ZONE SUMMARY ************************
Criterion maximum concentration (CMC)    =                 14 CFU-per-100mL
Corresponding dilution                   =            .0

The CMC value was not encountered within the specified simulation distance.
  Plume dilution values are too low to meet CMC.
********************** REGULATORY MIXING ZONE SUMMARY ***********************
No RMZ has been specified.
The CCC for the toxic pollutant was not encountered within the predicted
  plume region.
******************** FINAL DESIGN ADVICE AND COMMENTS ***********************
CORMIX2 uses the TWO-DIMENSIONAL SLOT DIFFUSER CONCEPT to represent
```

the actual three-dimensional diffuser geometry. Thus, it approximates the details of the merging process of the individual jets from each port/nozzle.
In the present design, the spacing between adjacent ports/nozzles (or riser assemblies) is of the order of, or less than, the local water depth so that the slot diffuser approximation holds well.
Nevertheless, if this is a final design, the user is advised to use a final CORMIX1 (single port discharge) analysis, with discharge data for an individual diffuser jet/plume, in order to compare to the present near-field prediction.

DIFFUSER DESIGN DETAILS: Because of the alternating arrangement of the opposing nozzles/ports, the AVERAGE VERTICAL ANGLE (THETA) has been set to 90 deg. This represents a ZERO NET HORIZONTAL MOMENTUM FLUX for the entire diffuser.

This parallel diffuser lies in CLOSE PROXIMITY to the bank (shoreline). The shoreline will act as a REFLECTING BOUNDARY for the flow field. This effect has been represented by doubling all flow variables.

REMINDER: The user must take note that HYDRODYNAMIC MODELING by any known technique is NOT AN EXACT SCIENCE.
Extensive comparison with field and laboratory data has shown that the CORMIX predictions on dilutions and concentrations (with associated plume geometries) are reliable for the majority of cases and are accurate to within about +-50% (standard deviation).
As a further safeguard, CORMIX will not give predictions whenever it judges the design configuration as highly complex and uncertain for prediction.

****

```
DESIGN CASE:                      Multiport discharge at 300m
FILE NAME:                        stage1ma
Subsystem CORMIX2:                Submerged Multiport Diffuser Discharges
END OF SESSION/ITERATION:         06/30/95--08:57:11
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
```

The Department of Civil Engineering
College of Engineering and Physical Sciences
The University of New Hampshire
Kingsbury Hall
33 College Road
Durham, New Hampshire 03824-3591

Project/Problem Set: Cormix Modeling
Detail/Problem: Stage 2 -
Class: ______ Prof: ______

Calc. by: Holly Clark
Date: 6/17/95
Chck. by: ______
Date: ______

Stage 2: Assume effluent is discharged from a multiport diffuser with 35 ports. The diffuser pipe is positioned along the center line of the channel with all the ports facing the same direction. The discharge from the ports is co-flowing with the water toward the mudflat. The "stream" is 500 m wide flowing west. Two simulations were run, once at a depth of 1 m and once at 1.5 m. The initial concentration of the effluent was the value taken as the fully mixed concentration from Stage 1. The density was assumed to match ambient.

Given: 2×10^9 CFU per vessel
35 vessels
Initial concentration = 5380 CFU/100mL

Find: Port diameter for 35 equal sized ports if discharge is continuous for 4 hrs. at a velocity of 0.1 m/s.

① finding volume, $\forall$

$$\forall = \frac{(2\times10^9\ \text{CFU})(35)}{5380\ \text{CFU}/100\ \text{mL}}\left(1\times10^{-6}\ \text{m}^3/\text{mL}\right) = 1301\ \text{m}^3$$

② finding total discharge, Q

$$Q = 1301\ \text{m}^3/4\ \text{hr}\,(3600\ \text{s/hr}) = 0.0903\ \text{m}^3/\text{s}$$

③ finding area of Port, A

$$A = \frac{Q}{V} = \frac{0.0903\ \text{m}^3/\text{s}}{0.1\ (35)} = 0.0258\ \text{m}^2/\text{port}$$

④ finding diameter of Port, d

$$d = \sqrt{\frac{4A}{\pi}} = 0.18\ \text{m}$$

CORMIX -- CORNELL MIXING ZONE EXPERT SYSTEM -- CORMIX

SITE Name: Seabrook Harbor Mudflat — Date: 6/17/95
Design CASE: multiport discharge over mudflat — Prepared by: [illegible]
DOS FILE NAME: Stage 2m (w/o extension)

AMBIENT DATA:

Water body depth	1 m	Water body is: bounded/unbounded (bounded circled)
Depth at discharge	1 m	If bounded: Width 500 m
		Appearance 1/2/3 (1 circled)
Ambient flowrate	____ m³/s or:	Ambient velocity 0.1 m/s
Manning's n	0.014 or:	Darcy-Weisbach f (0.015)
Wind speed	2 m/s	

Density data: — UNITS: Density...kg/m³ / Temperature...°C

Water body is	fresh/salt water (salt water circled)	If fresh: Specify as density/temp. values
If uniform: (circled)		Average density/temp. 1010.5
If stratified:		Density/temp. at surface ____
Stratification type	A/B/C	Density/temp. at bottom ____
If B/C: Pycnocline height	____ m	If C: Density/temp. jump ____

DISCHARGE DATA:

Specify **geometry** for CORMIX1 or 2 or 3

SUBMERGED SINGLE PORT DISCHARGE -- CORMIX1

Nearest bank is on	left/right	Distance to nearest bank ____ m
Vertical angle THETA	____ °	Horizontal angle SIGMA ____ °
Port diameter	____ m or:	Port area ____ m²
Port height	____ m	

SUBMERGED MULTIPORT DIFFUSER DISCHARGE -- CORMIX2

Nearest bank is on	left/right (left circled)	Distance to one endpoint 100 m
Diffuser length	300 m	to other endpoint 400 m
Total number of openings	35	
Port diameter	0.18 m	with contraction ratio 1
Diffuser arrangement/type	unidirectional (circled) / staged / alternating or vertical	A single port
Alignment angle GAMMA	90 °	Horizontal angle SIGMA 0 [illegible] °
Vertical angle THETA	0 ° [illegible]	Relative orientation BETA 90 °
Port height	.33 m	A unidirectional & same direction

BUOYANT SURFACE DISCHARGE -- CORMIX3

Discharge located on	left/right bank	Configuration flush/protruding/co-flowing
Horizontal angle SIGMA	____ °	If protruding: Dist. frm bank ____ m
Depth at discharge	____ m	Bottom slope ____ °
If rectangular Width	____ m or:	If circular Diameter ____ m
discharge channel: Depth	____ m	pipe: Bottom invert depth ____ m

Effluent: Flow rate	0.1 m³/s or:	Effluent velocity (0.11) m/s
Effluent density	1010.5 kg/m³ or:	Effluent temperature ____ °C
Heated discharge?	yes/no	If yes: Heat loss coefficient ____ W/m²,°C
Concentration units	CFU-Per-100mL	Effluent concentration 5380
Conservative substance?	yes/no (yes circled)	If no: Decay coefficient ____ /day

MIXING ZONE DATA:

Is effluent toxic?	yes/no (yes marked)	If yes: CMC value 14
		CCC value 14
WQ stand./conventional poll.?	yes/no (no circled)	If yes: value of standard ____
Any mixing zone specified?	yes/no (no circled)	If yes: distance ____ m
		or width ____ % or m
Region of interest	5000 m	or area ____ % or m²
Grid intervals for display	6	

A 12
(1 m)

```
CORMIX2 PREDICTION FILE:
22222222222222222222222222222222222222222222222222222222222222222222222222222
                      CORNELL MIXING ZONE EXPERT SYSTEM
Subsystem CORMIX2:                                            Subsystem version:
 Submerged Multiport Diffuser Discharges    CMX2 v.2.10               May 1993
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
CASE DESCRIPTION
 Site name/label:          Seabrook^Harbor^Mudflat
 Design case:              Multiport^discharge^over^mudflat
 FILE NAME:                cormix\sim\stage2m .cx2
 Time of Fortran run:      06/17/95--11:54:30

ENVIRONMENT PARAMETERS (metric units)
 Bounded section
 BS     =     500.00  AS     =      500.00  QA     =       50.00
 HA     =       1.00  HD     =        1.00
 UA     =       .100  F      =        .015  USTAR = .4384E-02
 UW     =      2.000  UWSTAR= .2198E-02
 Uniform density environment
 STRCND=  U           RHOAM = 1010.5000

DIFFUSER DISCHARGE PARAMETERS (metric units)
 DITYPE=unidirectional perpendicular
 BETYPE=unidirectional without fanning
 BANK   =  LEFT        DISTB =      250.00  YB1    =      100.00  YB2    =     400.00
 LD     =     300.00  NOPEN =   35          SPAC   =        8.82
 D0     =       .180  A0     =        .025  H0     =         .33
 GAMMA  =      90.00  THETA  =         .00
 SIGMA  =        .00  BETA   =       90.00
 U0     =       .112  Q0     =        .100         = .1000E+00
 RHO0   = 1010.5000   DRHO0  = .0000E+00   GP0    = .0000E+00
 C0     = .5380E+04   CUNITS=   CFU-per-100mL
 IPOLL  =  1          KS     = .0000E+00   KD     = .0000E+00

FLUX VARIABLES - PER UNIT DIFFUSER LENGTH (metric units)
 q0     = .3330E-03  m0     = .3738E-04  j0     = .0000E+00  SIGNJ0=       1.0
 Associated 2-d length scales (meters)
 lQ=B   =       .003  lM     =  99999.00  lm     =         .00
 lmp    =   99999.00  lbp    =  99999.00  la     =    99999.00

FLUX VARIABLES - ENTIRE DIFFUSER (metric units)
 Q0     = .1000E+00  M0     = .1121E-01  J0     = .0000E+00
 Associated 3-d length scales (meters)
 LQ     =        .95  LM     =  99999.00  Lm     =        1.05  Lb     =         .00
                                          Lmp    =    99999.00  Lbp    =    99999.00

NON-DIMENSIONAL PARAMETERS
 FR0    =   99999.00  FRD0   =  99999.00  R      =        1.12
 (slot)               (port/nozzle)

FLOW CLASSIFICATION
 2222222222222222222222222222222222222222
 2  Flow class (CORMIX2)        =    MU2    2
 2  Applicable layer depth HS =     1.00   2
 2222222222222222222222222222222222222222

MIXING ZONE / TOXIC DILUTION / REGION OF INTEREST PARAMETERS
 C0     = .5380E+04  CUNITS=   CFU-per-100mL
```

A13

(1m)

```
 NTOX   =  1          CMC    = .1400E+02  CCC    =  CSTD
 NSTD   =  1          CSTD   = .1400E+02
 REGMZ  =  0
 XINT   =    5000.00  XMAX   =    5000.00

X-Y-Z COORDINATE SYSTEM:
    ORIGIN is located at the bottom and the diffuser mid-point:
       250.00 m  from the LEFT  bank/shore.
    X-axis points downstream, Y-axis points to left, Z-axis points upward.
NSTEP =  6 display intervals per module
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD201: DIFFUSER DISCHARGE MODULE

 Profile definitions:
   BV = Gaussian 1/e (37%) half-width, in vertical plane normal to trajectory
   BH = top-hat half-width, in horizontal plane normal to trajectory
   S  = hydrodynamic centerline dilution
   C  = centerline concentration (includes reaction effects, if any)

       X         Y        Z         S        C        BV       BH
      .00       .00      .33       1.0  .538E+04     .00    150.00

END OF MOD201: DIFFUSER DISCHARGE MODULE
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD271: ACCELERATION ZONE OF UNIDIRECTIONAL CO-FLOWING DIFFUSER

 In this laterally contracting zone the diffuser plume becomes VERTICALLY FULLY
  MIXED over the entire layer depth (HS =    1.00m).
   Full mixing is achieved after a plume distance of about five
   layer depths from the diffuser.

 Profile definitions:
   BV = layer depth (vertically mixed)
   BH = top-hat half-width, in horizontal plane normal to trajectory
   S  = hydrodynamic average (bulk) dilution
   C  = average (bulk) concentration (includes reaction effects, if any)

       X         Y        Z         S        C        BV       BH
      .00       .00     1.00       1.0  .538E+04    1.00    150.00
    25.00       .00     1.00     302.3  .178E+02    1.00    149.89
    50.00       .00     1.00     302.3  .178E+02    1.00    149.82
    75.00       .00     1.00     302.3  .178E+02    1.00    149.77
   100.00       .00     1.00     302.3  .178E+02    1.00    149.74
   125.00       .00     1.00     302.3  .178E+02    1.00    149.73
   150.00       .00     1.00     302.3  .178E+02    1.00    149.72
 Cumulative travel time =          1494. sec

END OF MOD271: ACCELERATION ZONE OF UNIDIRECTIONAL CO-FLOWING DIFFUSER
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD251: DIFFUSER PLUME IN CO-FLOW

 Phase 1: Vertically mixed, Phase 2: Re-stratified

 Phase 1: The diffuser plume is VERTICALLY FULLY MIXED over the
          entire layer depth.
 This flow region is INSIGNIFICANT in spatial extent and will be by-passed.
-----------------------------------------------------------------------------
```

A14

(1m)

Phase 2: The flow has RESTRATIFIED at the beginning of this zone.

This flow region is INSIGNIFICANT in spatial extent and will be by-passed.

END OF MOD251: DIFFUSER PLUME IN CO-FLOW

** End of NEAR-FIELD REGION (NFR) **

BEGIN MOD241: BUOYANT AMBIENT SPREADING

Discharge is non-buoyant or weakly buoyant.
Therefore BUOYANT SPREADING REGIME is ABSENT.

END OF MOD241: BUOYANT AMBIENT SPREADING

BEGIN MOD261: PASSIVE AMBIENT MIXING IN UNIFORM AMBIENT

Vertical diffusivity (initial value) = .913E-03 m^2/s
Horizontal diffusivity (initial value) = .114E-02 m^2/s

The passive diffusion plume is VERTICALLY FULLY MIXED at beginning of region.

Profile definitions:
BV = Gaussian s.d.*sqrt(pi/2) (46%) thickness, measured vertically
= or equal to layer depth, if fully mixed
BH = Gaussian s.d.*sqrt(pi/2) (46%) half-width,
measured horizontally in Y-direction
ZU = upper plume boundary (Z-coordinate)
ZL = lower plume boundary (Z-coordinate)
S = hydrodynamic centerline dilution
C = centerline concentration (includes reaction effects, if any)

Plume Stage 1 (not bank attached):

X	Y	Z	S	C	BV	BH	ZU	ZL
150.00	.00	1.00	302.3	.178E+02	1.00	151.16	1.00	.00
958.33	.00	1.00	302.5	.178E+02	1.00	151.26	1.00	.00
1766.67	.00	1.00	302.7	.178E+02	1.00	151.35	1.00	.00
2575.00	.00	1.00	302.9	.178E+02	1.00	151.45	1.00	.00
3383.33	.00	1.00	303.1	.178E+02	1.00	151.54	1.00	.00
4191.67	.00	1.00	303.3	.177E+02	1.00	151.64	1.00	.00
5000.00	.00	1.00	303.5	.177E+02	1.00	151.73	1.00	.00

Cumulative travel time = 49994. sec

Simulation limit based on maximum specified distance = 5000.00 m.
This is the REGION OF INTEREST limitation.

END OF MOD261: PASSIVE AMBIENT MIXING IN UNIFORM AMBIENT

Because of the fairly LARGE SPACING between adjacent risers/nozzles/ports,
the above results may be unreliable in the immediate near-field of
the diffuser.
A SUBSEQUENT APPLICATION OF CORMIX1 IS RECOMMENDED to provide more detail
for one of the individual jets/plumes in the initial region
before merging.

CORMIX2: Submerged Multiport Diffuser Discharges End of Prediction File
2222222222222222222222222222222222222222222222222222222222222222222222222

CORMIX SESSION REPORT:
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

```
                  CORMIX: CORNELL MIXING ZONE EXPERT SYSTEM
                      CORMIX v.2.10          May 1993
SITE NAME/LABEL:                   Seabrook Harbor Mudflat
  DESIGN CASE:                     Multiport discharge over mudflat
  FILE NAME:                       stage2m
Using subsystem CORMIX2:           Submerged Multiport Diffuser Discharges
  Start of session:                06/17/95--11:34:05
******************************************************************************
SUMMARY OF INPUT DATA:
------------------------------------------------------------------------------
AMBIENT PARAMETERS:
  Cross-section                             = bounded
  Width                          BS         =         500 m
  Channel regularity                        = 1
  Ambient flowrate               QA         =          50 m^3/s
  Average depth                  HA         =           1 m
  Depth at discharge             HD         =           1 m
  Ambient velocity               UA         =          .1 m/s
  Darcy-Weisbach friction factor F          =      0.0153
    Calculated from Manning's n             =        .014
  Wind velocity                  UW         =           2 m/s
Stratification Type              STRCND = U
  Surface density                RHOAS      =      1010.5 kg/m^3
  Bottom density                 RHOAB      =      1010.5 kg/m^3
------------------------------------------------------------------------------
DISCHARGE PARAMETERS:            Submerged Multiport Diffuser Discharge
  Diffuser type                  DITYPE = unidirectional perpendicular
  Diffuser length                LD         = 300 m
  Nearest bank                              = left
  Diffuser endpoints             YB1        =    100 m;    YB2 =     400 m
  Number of openings             NOPEN      =          35
  Spacing between risers/openings SPAC      =        8.82 m
  Port/Nozzle diameter           D0         =         .18 m
  Equivalent slot width          B0         =      0.0029 m
  Total area of openings         A0         =      0.0254 m^2
  Discharge velocity             U0         =        0.11 m/s
  Total discharge                Q0         =          .1 m^3/s
  Discharge port height          H0         =         .33 m
  Nozzle arrangement             BETYPE = unidirectional without fanning
  Diffuser alignment angle       GAMMA      =          90 deg
  Vertical discharge angle       THETA      =           0 deg
  Horizontal discharge angle     SIGMA      =           0 deg
  Relative orientation angle     BETA       =          90 deg
  Discharge density              RHO0       =      1010.5 kg/m^3
  Density difference             DRHO       =           0 kg/m^3
  Buoyant acceleration           GP0        =       .0000 m/s^2
  Discharge concentration        C0         =             5380 CFU-per-100mL
  Surface heat exchange coeff.   KS         =           0 m/s
  Coefficient of decay           KD         =           0 /s
------------------------------------------------------------------------------
FLUX VARIABLES PER UNIT DIFFUSER LENGTH:
  Discharge (volume flux)        q0         =    0.000333 m^2/s
  Momentum flux                  m0         =    0.000037 m^3/s^2
  Buoyancy flux                  j0         =           0 m^3/s^3
------------------------------------------------------------------------------
DISCHARGE/ENVIRONMENT LENGTH SCALES :
  lq  =       0.00 m       lm  =       0.00 m        lM =     99999.0 m
```

A16 (1m)

```
  lm' =    99999.0 m          lb' =    99999.0 m          la =    99999.0 m
  (These refer to the actual discharge/environment length scales.)
-----------------------------------------------------------------------------
NON-DIMENSIONAL PARAMETERS:
  Slot Froude number                FR0     =    99999.0
  Port/nozzle Froude number         FRD0    =    99999.0
  Velocity ratio                    R       =       1.12
-----------------------------------------------------------------------------
MIXING ZONE / TOXIC DILUTION ZONE / AREA OF INTEREST PARAMETERS:
  Toxic discharge                           = yes
  CMC concentration                 CMC     =                14 CFU-per-100mL
  CCC concentration                 CCC     =                14 CFU-per-100mL
  Water quality standard                    = given by CCC value
  Regulatory mixing zone                    = no
  Region of interest                        =      5000.00 m downstream
*****************************************************************************
HYDRODYNAMIC CLASSIFICATION:
  *------------------------*
  | FLOW CLASS    =    MU2 |
  *------------------------*
  This flow configuration applies to a layer corresponding to the full water
  depth at the discharge site.
  Applicable layer depth = water depth =           1 m
*****************************************************************************
MIXING ZONE EVALUATION (hydrodynamic and regulatory summary):
-----------------------------------------------------------------------------
X-Y-Z Coordinate system:
  Origin is located at the bottom below the port center:
           250 m from the left bank/shore.
-----------------------------------------------------------------------------
NEAR-FIELD REGION (NFR) CONDITIONS :
Note: The NFR is the zone of strong initial mixing.  It has no regulatory
  implication.  However, this information may be useful for the discharge
  designer because the mixing in the NFR is usually sensitive to the
  discharge design conditions.
  Pollutant concentration at edge of NFR =        17.7957 CFU-per-100mL
  Dilution at edge of NFR                =       302.3
  NFR Location:                        x =      150.00 m
    (centerline coordinates)           y =         .00 m
                                       z =        1.00 m
  NFR plume dimensions:       half-width =      149.72 m
                               thickness =        1.00 m
-----------------------------------------------------------------------------
Buoyancy assessment:
  The effluent density is equal or about about equal to the surrounding
  ambient water density at the discharge level.
  Therefore, the effluent behaves essentially as NEUTRALLY BUOYANT.
-----------------------------------------------------------------------------
Near-field instability behavior:
  The diffuser flow will experience instabilities with full vertical mixing
  in the near-field.
  There may be benthic impact of high pollutant concentrations.
-----------------------------------------------------------------------------
FAR-FIELD MIXING SUMMARY:
  Plume becomes vertically fully mixed at      150.00 m downstream.
*********************** TOXIC DILUTION ZONE SUMMARY ***********************
Criterion maximum concentration (CMC)     =               14 CFU-per-100mL
Corresponding dilution                    =            .0

The CMC value was not encountered within the specified simulation distance.
```

Plume dilution values are too low to meet CMC.

********************** REGULATORY MIXING ZONE SUMMARY ***********************

No RMZ has been specified.

The CCC for the toxic pollutant was not encountered within the predicted plume region.

********************* FINAL DESIGN ADVICE AND COMMENTS ***********************

CORMIX2 uses the TWO-DIMENSIONAL SLOT DIFFUSER CONCEPT to represent the actual three-dimensional diffuser geometry. Thus, it approximates the details of the merging process of the individual jets from each port/nozzle.

In the present design, the spacing between adjacent ports/nozzles (or riser assemblies) is somewhat greater (in the range between three times to ten times) the local water depth. It is unlikely that sufficient lateral interaction of adjacent jets will occur in the near-field. However, the individual jets/plumes may merge soon after in the intermediate-field or in the far-field.

CORMIX2 may have LIMITED APPLICABILITY for this discharge situation. The results may be somewhat unrealistic in the near-field (minimum dilution may be overpredicted), but appear to be applicable for the intermediate- and far-field processes.

The user is advised to use a subsequent CORMIX1 (single port discharge) analysis, using discharge data for an individual diffuser jet/plume, in order to compare to the present near-field prediction.

REMINDER: The user must take note that HYDRODYNAMIC MODELING by any known technique is NOT AN EXACT SCIENCE.

Extensive comparison with field and laboratory data has shown that the CORMIX predictions on dilutions and concentrations (with associated plume geometries) are reliable for the majority of cases and are accurate to within about +-50% (standard deviation).

As a further safeguard, CORMIX will not give predictions whenever it judges the design configuration as highly complex and uncertain for prediction.

****

DESIGN CASE: Multiport discharge over mudflat
FILE NAME: stage2m
Subsystem CORMIX2: Submerged Multiport Diffuser Discharges
END OF SESSION/ITERATION: 06/30/95--09:01:00

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

A18 (1.5m)

```
CORMIX2 PREDICTION FILE:
2222222222222222222222222222222222222222222222222222222222222222222222222222222
                      CORNELL MIXING ZONE EXPERT SYSTEM
Subsystem CORMIX2:                                            Subsystem version:
 Submerged Multiport Diffuser Discharges     CMX2 v.2.10               May 1993
-------------------------------------------------------------------------------
-------------------------------------------------------------------------------
CASE DESCRIPTION
 Site name/label:          Seabrook^Harbor^Mudflat
 Design case:              Multiport^discharge^over^one^and^a^half^
 FILE NAME:                cormix\sim\stage2mb.cx2
 Time of Fortran run:      06/17/95--12:00:20

ENVIRONMENT PARAMETERS (metric units)
 Bounded section
 BS     =     500.00  AS     =     750.00  QA     =      75.00
 HA     =       1.50  HD     =       1.50
 UA     =       .100  F      =       .013  USTAR = .4098E-02
 UW     =      2.000  UWSTAR= .2198E-02
 Uniform density environment
 STRCND=  U           RHOAM = 1010.5000

DIFFUSER DISCHARGE PARAMETERS (metric units)
 DITYPE=unidirectional perpendicular
 BETYPE=unidirectional without fanning
 BANK   =  LEFT       DISTB =     250.00  YB1    =     100.00  YB2    =     400.00
 LD     =     300.00  NOPEN =   35        SPAC   =       8.82
 D0     =       .180  A0     =       .025  H0     =        .33
 GAMMA =      90.00  THETA =        .00
 SIGMA =        .00  BETA   =      90.00
 U0     =       .112  Q0     =       .100         = .1000E+00
 RHO0   = 1010.5000  DRHO0 = .0000E+00  GP0    = .0000E+00
 C0     = .5380E+04  CUNITS=  CFU-per-100mL
 IPOLL =  1          KS     = .0000E+00  KD     = .0000E+00

FLUX VARIABLES - PER UNIT DIFFUSER LENGTH (metric units)
 q0     = .3330E-03  m0     = .3738E-04  j0     = .0000E+00  SIGNJ0=       1.0
 Associated 2-d length scales (meters)
 lQ=B   =       .003 lM     =   99999.00 lm     =        .00
 lmp    =   99999.00 lbp    =   99999.00 la     =   99999.00

FLUX VARIABLES - ENTIRE DIFFUSER (metric units)
 Q0     = .1000E+00  M0     = .1121E-01  J0     = .0000E+00
 Associated 3-d length scales (meters)
 LQ     =        .95 LM     =   99999.00 Lm     =       1.05  Lb     =        .00
                                         Lmp    =   99999.00  Lbp    =   99999.00

NON-DIMENSIONAL PARAMETERS
 FR0    =   99999.00 FRD0   =   99999.00 R      =       1.12
 (slot)              (port/nozzle)

FLOW CLASSIFICATION
 2222222222222222222222222222222222222222
 2  Flow class (CORMIX2)      =     MU2    2
 2  Applicable layer depth HS =     1.50   2
 2222222222222222222222222222222222222222

MIXING ZONE / TOXIC DILUTION / REGION OF INTEREST PARAMETERS
 C0     = .5380E+04  CUNITS=  CFU-per-100mL
```

A19
(1.5 m)

```
 NTOX  =  1          CMC   = .1400E+02  CCC   =  CSTD
 NSTD  =  1          CSTD  = .1400E+02
 REGMZ =  0
 XINT  =   5000.00  XMAX  =   5000.00

X-Y-Z COORDINATE SYSTEM:
    ORIGIN is located at the bottom and the diffuser mid-point:
       250.00 m  from the LEFT  bank/shore.
    X-axis points downstream, Y-axis points to left, Z-axis points upward.
NSTEP =  6 display intervals per module
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD201: DIFFUSER DISCHARGE MODULE

 Profile definitions:
   BV = Gaussian 1/e (37%) half-width, in vertical plane normal to trajectory
   BH = top-hat half-width, in horizontal plane normal to trajectory
   S  = hydrodynamic centerline dilution
   C  = centerline concentration (includes reaction effects, if any)

       X         Y        Z        S       C        BV       BH
      .00       .00      .33      1.0  .538E+04    .00    150.00

END OF MOD201: DIFFUSER DISCHARGE MODULE
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD271: ACCELERATION ZONE OF UNIDIRECTIONAL CO-FLOWING DIFFUSER

 In this laterally contracting zone the diffuser plume becomes VERTICALLY FULLY
  MIXED over the entire layer depth (HS =    1.50m).
   Full mixing is achieved after a plume distance of about five
   layer depths from the diffuser.

 Profile definitions:
   BV = layer depth (vertically mixed)
   BH = top-hat half-width, in horizontal plane normal to trajectory
   S  = hydrodynamic average (bulk) dilution
   C  = average (bulk) concentration (includes reaction effects, if any)

       X         Y        Z        S       C        BV       BH
      .00       .00     1.50      1.0  .538E+04   1.50    150.00
** CMC HAS BEEN FOUND **
 The pollutant concentration in the plume falls below CMC value of  .140E+02
   in the current prediction interval.
 This is the extent of the TOXIC DILUTION ZONE.
** WATER QUALITY STANDARD OR CCC HAS BEEN FOUND **
 The pollutant concentration in the plume falls below water quality standard
   or CCC value of  .140E+02 in the current prediction interval.
 This is the spatial extent of concentrations exceeding the water quality
   standard or CCC value.
     25.00       .00     1.50    453.2  .119E+02   1.50    149.93
     50.00       .00     1.50    453.2  .119E+02   1.50    149.88
     75.00       .00     1.50    453.2  .119E+02   1.50    149.85
    100.00       .00     1.50    453.2  .119E+02   1.50    149.83
    125.00       .00     1.50    453.2  .119E+02   1.50    149.82
    150.00       .00     1.50    453.2  .119E+02   1.50    149.82
 Cumulative travel time =          1496. sec

END OF MOD271: ACCELERATION ZONE OF UNIDIRECTIONAL CO-FLOWING DIFFUSER
-----------------------------------------------------------------------------
```

BEGIN MOD251: DIFFUSER PLUME IN CO-FLOW

Phase 1: Vertically mixed, Phase 2: Re-stratified

Phase 1: The diffuser plume is VERTICALLY FULLY MIXED over the entire layer depth.
This flow region is INSIGNIFICANT in spatial extent and will be by-passed.

Phase 2: The flow has RESTRATIFIED at the beginning of this zone.

This flow region is INSIGNIFICANT in spatial extent and will be by-passed.

END OF MOD251: DIFFUSER PLUME IN CO-FLOW

** End of NEAR-FIELD REGION (NFR) **

BEGIN MOD241: BUOYANT AMBIENT SPREADING

Discharge is non-buoyant or weakly buoyant.
Therefore BUOYANT SPREADING REGIME is ABSENT.

END OF MOD241: BUOYANT AMBIENT SPREADING

BEGIN MOD261: PASSIVE AMBIENT MIXING IN UNIFORM AMBIENT

Vertical diffusivity (initial value) = .129E-02 m^2/s
Horizontal diffusivity (initial value) = .161E-02 m^2/s

The passive diffusion plume is VERTICALLY FULLY MIXED at beginning of region.

Profile definitions:
BV = Gaussian s.d.*sqrt(pi/2) (46%) thickness, measured vertically
   = or equal to layer depth, if fully mixed
BH = Gaussian s.d.*sqrt(pi/2) (46%) half-width,
     measured horizontally in Y-direction
ZU = upper plume boundary (Z-coordinate)
ZL = lower plume boundary (Z-coordinate)
S = hydrodynamic centerline dilution
C = centerline concentration (includes reaction effects, if any)

Plume Stage 1 (not bank attached):

X	Y	Z	S	C	BV	BH	ZU	ZL
150.00	.00	1.50	453.2	.119E+02	1.50	151.07	1.50	.00
958.33	.00	1.50	453.6	.119E+02	1.50	151.20	1.50	.00
1766.67	.00	1.50	454.0	.118E+02	1.50	151.34	1.50	.00
2575.00	.00	1.50	454.4	.118E+02	1.50	151.47	1.50	.00
3383.33	.00	1.50	454.8	.118E+02	1.50	151.61	1.50	.00
4191.67	.00	1.50	455.2	.118E+02	1.50	151.74	1.50	.00
5000.00	.00	1.50	455.6	.118E+02	1.50	151.88	1.50	.00

Cumulative travel time = 49996. sec

Simulation limit based on maximum specified distance = 5000.00 m.
This is the REGION OF INTEREST limitation.

END OF MOD261: PASSIVE AMBIENT MIXING IN UNIFORM AMBIENT

Because of the fairly LARGE SPACING between adjacent risers/nozzles/ports, A21 (9.5m)

```
  the above results may be unreliable in the immediate near-field of
  the diffuser.
A SUBSEQUENT APPLICATION OF CORMIX1 IS RECOMMENDED to provide more detail
  for one of the individual jets/plumes in the initial region
before merging.
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
CORMIX2: Submerged Multiport Diffuser Discharges       End of Prediction File
22222222222222222222222222222222222222222222222222222222222222222222222222222
```

A22
(1.5 m)

CORMIX SESSION REPORT:
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

```
             CORMIX: CORNELL MIXING ZONE EXPERT SYSTEM
                 CORMIX v.2.10          May 1993
SITE NAME/LABEL:                Seabrook Harbor Mudflat
  DESIGN CASE:                  Multiport discharge over one and a half m
  FILE NAME:                    stage2mb
Using subsystem CORMIX2:        Submerged Multiport Diffuser Discharges
  Start of session:             06/17/95--11:59:22
*****************************************************************************
SUMMARY OF INPUT DATA:
-----------------------------------------------------------------------------
AMBIENT PARAMETERS:
  Cross-section                          = bounded
  Width                            BS    =          500 m
  Channel regularity                     = 1
  Ambient flowrate                 QA    =           75 m^3/s
  Average depth                    HA    =          1.5 m
  Depth at discharge               HD    =          1.5 m
  Ambient velocity                 UA    =           .1 m/s
  Darcy-Weisbach friction factor   F     =       0.0134
    Calculated from Manning's n          =         .014
  Wind velocity                    UW    =            2 m/s
Stratification Type                STRCND = U
  Surface density                  RHOAS  =      1010.5 kg/m^3
  Bottom density                   RHOAB  =      1010.5 kg/m^3
-----------------------------------------------------------------------------
DISCHARGE PARAMETERS:              Submerged Multiport Diffuser Discharge
  Diffuser type                    DITYPE = unidirectional perpendicular
  Diffuser length                  LD     = 300 m
  Nearest bank                            = left
  Diffuser endpoints               YB1    =      100 m;    YB2 =     400 m
  Number of openings               NOPEN  =          35
  Spacing between risers/openings  SPAC   =        8.82 m
  Port/Nozzle diameter             D0     =         .18 m
  Equivalent slot width            B0     =      0.0029 m
  Total area of openings           A0     =      0.0254 m^2
  Discharge velocity               U0     =        0.11 m/s
  Total discharge                  Q0     =          .1 m^3/s
  Discharge port height            H0     =         .33 m
  Nozzle arrangement               BETYPE = unidirectional without fanning
  Diffuser alignment angle         GAMMA  =          90 deg
  Vertical discharge angle         THETA  =           0 deg
  Horizontal discharge angle       SIGMA  =           0 deg
  Relative orientation angle       BETA   =          90 deg
  Discharge density                RHO0   =      1010.5 kg/m^3
  Density difference               DRHO   =           0 kg/m^3
  Buoyant acceleration             GP0    =       .0000 m/s^2
  Discharge concentration          C0     =             5380 CFU-per-100mL
  Surface heat exchange coeff.     KS     =           0 m/s
  Coefficient of decay             KD     =           0 /s
-----------------------------------------------------------------------------
FLUX VARIABLES PER UNIT DIFFUSER LENGTH:
  Discharge (volume flux)          q0     =    0.000333 m^2/s
  Momentum flux                    m0     =    0.000037 m^3/s^2
  Buoyancy flux                    j0     =           0 m^3/s^3
-----------------------------------------------------------------------------
DISCHARGE/ENVIRONMENT LENGTH SCALES :
  lq  =       0.00 m       lm  =        0.00 m        lM  =    99999.0 m
```

A 23
(1.5 m)

```
 lm' =     99999.0 m          lb' =     99999.0 m          la =     99999.0 m
 (These refer to the actual discharge/environment length scales.)
-----------------------------------------------------------------------------
NON-DIMENSIONAL PARAMETERS:
 Slot Froude number                 FR0      =     99999.0
 Port/nozzle Froude number          FRD0     =     99999.0
 Velocity ratio                     R        =        1.12
-----------------------------------------------------------------------------
MIXING ZONE / TOXIC DILUTION ZONE / AREA OF INTEREST PARAMETERS:
 Toxic discharge                             = yes
 CMC concentration                  CMC      =              14 CFU-per-100mL
 CCC concentration                  CCC      =              14 CFU-per-100mL
 Water quality standard                      = given by CCC value
 Regulatory mixing zone                      = no
 Region of interest                          =      5000.00 m downstream
*****************************************************************************
HYDRODYNAMIC CLASSIFICATION:
 *------------------------*
 | FLOW CLASS   =     MU2 |
 *------------------------*
 This flow configuration applies to a layer corresponding to the full water
 depth at the discharge site.
 Applicable layer depth = water depth =          1.5 m
*****************************************************************************
MIXING ZONE EVALUATION (hydrodynamic and regulatory summary):
-----------------------------------------------------------------------------
X-Y-Z Coordinate system:
 Origin is located at the bottom below the port center:
            250 m from the left bank/shore.
-----------------------------------------------------------------------------
NEAR-FIELD REGION (NFR) CONDITIONS :
Note: The NFR is the zone of strong initial mixing.  It has no regulatory
 implication.  However, this information may be useful for the discharge
 designer because the mixing in the NFR is usually sensitive to the
 discharge design conditions.
 Pollutant concentration at edge of NFR =          11.8711 CFU-per-100mL
 Dilution at edge of NFR                =        453.2
 NFR Location:                        x =       150.00 m
   (centerline coordinates)           y =          .00 m
                                      z =         1.50 m
 NFR plume dimensions:       half-width =       149.81 m
                              thickness =         1.50 m
-----------------------------------------------------------------------------
Buoyancy assessment:
 The effluent density is equal or about about equal to the surrounding
 ambient water density at the discharge level.
 Therefore, the effluent behaves essentially as NEUTRALLY BUOYANT.
-----------------------------------------------------------------------------
Near-field instability behavior:
 The diffuser flow will experience instabilities with full vertical mixing
 in the near-field.
 There may be benthic impact of high pollutant concentrations.
-----------------------------------------------------------------------------
FAR-FIELD MIXING SUMMARY:
 Plume becomes vertically fully mixed at       150.00 m downstream.
*********************** TOXIC DILUTION ZONE SUMMARY ************************
Recall: The TDZ corresponds to the three (3) criteria issued in the USEPA
 Technical Support Document (TSD) for Water Quality-based Toxics Control,
 1991 (EPA/505/2-90-001).
 Criterion maximum concentration (CMC)  =              14 CFU-per-100mL
```

A24
(1.5m)

```
  Corresponding dilution                        =        384.2
 The CMC was encountered at the following plume position:
  Plume location:                             x =         24.99 m
    (centerline coordinates)                  y =           .00 m
                                              z =          1.50 m
  Plume dimensions:                  half-width =        149.92 m
                                      thickness =          1.50 m
 CRITERION 1: This location is beyond 50 times the discharge length scale of
              Lq = 0.159480 m.
 +++++++++ The discharge length scale TEST for the TDZ has FAILED. ++++++++++

 CRITERION 2: This location is beyond 5 times the ambient water depth
              HD =          1.5 m.
 +++++++++++++ The ambient depth TEST for the TDZ has FAILED. +++++++++++++++

 CRITERION 3: No RMZ has been defined.  Therefore, the Regulatory Mixing zone
              test for the TDZ cannot be applied.
 The diffuser discharge velocity is equal to         0.11 m/s.
   This is less than the minimum of 3.0 m/s recommended in the TSD.
 +++ The discharge velocity RECOMMENDATION for the TDZ has NOT been met. ++++

 **** This discharge DOES NOT SATISFY all three CMC criteria for TDZ.   *****
 **** This MAY be caused by the low discharge velocity for this design. *****
********************** REGULATORY MIXING ZONE SUMMARY ***********************
No RMZ has been specified.
However:
The CCC was encountered at the following plume position:
The CCC for the toxic pollutant was encountered at the following
  plume position:
  CCC                                           =             14 CFU-per-100mL
  Corresponding dilution                        =        384.2
  Plume location:                             x =         24.99 m
    (centerline coordinates)                  y =           .00 m
                                              z =          1.50 m
  Plume dimensions:                  half-width =        149.92 m
                                      thickness =          1.50 m
********************** FINAL DESIGN ADVICE AND COMMENTS **********************
CORMIX2 uses the TWO-DIMENSIONAL SLOT DIFFUSER CONCEPT to represent
  the actual three-dimensional diffuser geometry.  Thus, it approximates
  the details of the merging process of the individual jets from each
  port/nozzle.
In the present design, the spacing between adjacent ports/nozzles
  (or riser assemblies) is somewhat greater (in the range between
  three times to ten times) the local water depth.  It is unlikely
  that sufficient lateral interaction of adjacent jets will
  occur in the near-field.  However, the individual jets/plumes may merge
  soon after in the intermediate-field or in the far-field.

CORMIX2 may have LIMITED APPLICABILITY for this discharge situation.
  The results may be somewhat unrealistic in the near-field (minimum
  dilution may be overpredicted), but appear to be applicable for the
  intermediate- and far-field processes.
The user is advised to use a subsequent CORMIX1 (single port discharge)
  analysis, using discharge data for an individual diffuser jet/plume,
  in order to compare to the present near-field prediction.
-----------------------------------------------------------------------------
REMINDER:  The user must take note that HYDRODYNAMIC MODELING by any known
  technique is NOT AN EXACT SCIENCE.
Extensive comparison with field and laboratory data has shown that the
  CORMIX predictions on dilutions and concentrations (with associated
```

plume geometries) are reliable for the majority of cases and are accurate
to within about +-50% (standard deviation).
As a further safeguard, CORMIX will not give predictions whenever it judges the design configuration as highly complex and uncertain for prediction.
****

```
DESIGN CASE:                    Multiport discharge over one and a half m
FILE NAME:                      stage2mb
Subsystem CORMIX2:              Submerged Multiport Diffuser Discharges
END OF SESSION/ITERATION:       06/30/95--09:04:54
```

XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX

Appendix B

The Department of Civil Engineering
College of Engineering and Physical Sciences
The University of New Hampshire
Kingsbury Hall
33 College Road
Durham, New Hampshire 03824-3591

Project/Problem Set: Slug Injection
Detail/Problem:
Class: Prof:

Calc. by: Holly Clark
Date: 6/17/95
Chck. by:
Date:

Given: Mass of slug = 2×10^9 CFU
Velocity = 0.1 m/s
Channel is 96 m wide × 3 m deep × 500 m long

Find: Concentration of fecal coliform using a stream dispersion equation

Theory: McQuivey and Keefer dispersion coefficient equation:

$D_L = 0.058 \cdot Q/(S_o w)$ Q = discharge, S_o = bedslope, w = stream width

Stream dispersion equation for concentration:

$$C(x,t) = \frac{M}{A(4\pi D_L t)^{1/2}} \exp^{-}\left[\frac{(x - vt)^2}{4 D_L t}\right]$$

Assumptions: $S_o = 0.001$
Formula is valid for reach not less than 7 stream widths.

① finding discharge, Q

$$Q = VA = (0.1 \text{ m/s})(96 \text{ m} \times 3 \text{ m}) = 28.8 \text{ m}^3/\text{s}$$

② finding dispersion coefficient, D_L

$$D_L = \frac{0.058\,(28.8)}{(0.001)(96)} = 17.4 \ \frac{\text{m}^2}{\text{s}}$$

check: at t = 3600 s x = 360 m width = $x/7$ = $360/7$ = 51

$$C(360\text{ m}, 3600\text{ s}) = \frac{2 \times 10^9 \text{ CFU}}{(10^4 \frac{100\text{mL}}{\text{m}^3})(51 \times 3)(4\pi\ 17.4\ (3600))^{1/2}} \exp^{-}\left[\frac{(360 - 3600(0.1))^2}{4\,(17.4)\,3600}\right] = 1.4 \ \frac{\text{CFU}}{100\text{mL}}$$

result: The peak concentration of 1.4 CFU/100mL is 360 m downstream one hour after release.

If the slug is fully mixed along the reach:

$$C = \frac{2 \times 10^9 \text{ CFU}}{(96 \times 3)(360 \text{ m})(10^4 \frac{100\text{mL}}{\text{m}^3})} = 1.93 \text{ CFU}/100\text{mL}$$

	The Department of Civil Engineering College of Engineering and Physical Sciences The University of New Hampshire Kingsbury Hall 33 College Road Durham, New Hampshire 03824-3591	Project/Problem Set: Slug injection Detail/Problem: Class: Prof:	Sheet: R2 of 3 Calc. by: Hilly Clark Date: 6/17/95 Chck. by: Date:

③ finding peak concentration at 48 m from slug injection

$A = 48/7 \times 3\text{ m} = 20.6\text{ m}^2$

$x = 48\text{ m}$

$V = 0.1\text{ m/s}$

$t = 480\text{ s}$

$$x - vt = 0 \;\therefore\; \exp\left[\frac{(x-vt)^2}{4D_L t}\right] = 1$$

$$C(48\text{m}, 480\text{s}) = \frac{2\times10^{9}\text{ CFU }(10^{-4}\text{ m}^3/100\text{ mL})}{(20.6\text{m}^2)(4\pi(17.4)(480))^{1/2}} = \underline{\underline{30.0\text{ CFU}/100\text{ mL}}}$$

Given: Slug injection of 2×10^9 CFU $= C_i \forall_i$
Depth of channel is 3 m

Find: Volume of water required to fully mix the slug injection to 14 CFU/100 mL concentration (C_f). Find dimensions.

Assume: Ambient water has a 0 CFU/100mL concentration $= C_o$

① finding volume required to fully mix to 14 CFU/100mL concentration, $\forall_f$

$$C_i \forall_i + \cancel{C_o \forall_o}^{0} = C_f \forall_f$$

$$\forall_f = \frac{C_i \forall_i}{C_f} = \frac{2 \times 10^9 \text{ CFU}}{14 \text{ CFU}/100\text{mL}} \left(\frac{1 \times 10^{-4} \text{ m}^3}{100 \text{ mL}} \right) = 14286 \text{ m}^3$$

② finding radius of cylinder

$$\frac{14286 \text{ m}^3}{3 \text{m}} = 4762 \text{ m}^2$$

$$r = \left[\frac{4762}{\pi} \right]^{1/2} = 39 \text{ m}$$

If the discharge from the vessel was fully mixed to 14 CFU/100 mL it would spread the full depth of 3 m and reach to a radius of 39 m from the point of injection.
If the mud-flat is 48 m from the mooring, the fully mixed region would have to move 9 m to hit the mudflat. At 0.1 m/s velocity, it would move 9 m in 90 seconds or 1.5 minutes.
Even if it mixes as it moves, this illustrates the extent of mixing that must occur in a relatively short time.

APPENDIX III

CORMIX Model and Slug Injection Evaluation Using a Decay Coeficient for Bacterial Die-off

Addendum to the Diffusion Study on Contamination of the Seabrook Clamflat in Hampton Harbor

Holly C. Gallagher

Report Prepared for:

Dr. Richard Langan
June 30, 1995

Fluids Lab Graduate Office
Department of Civil Engineering
Kingsbury Hall
Durham, NH 03824

June 30, 1995

Dr. Richard Langan
Jackson Estuarine Laboratory
Durham, NH 03824

Subject: Addendum to the Diffusion Study on Contamination of the Seabrook Clamflat in Hampton Harbor

Dear Dr. Langan:

The Seabrook area of the Hampton Harbor was re-evaluated incorporating two changes per your suggestion. A decay coefficient of 10 day^{-1} was added to the model parameters. A velocity vector that results from a 10 cm/s westerly flow and a 30 cm/s southerly flow was calculated and also added. The CORMIX computer model and an advection-dispersion model were used to evaluate the diffusion of discharges from moored vessels in the channel.

The CORMIX modeling estimated the fecal coliform count to be below 0.018 CFU/100mL as it flowed over the mudflat. A slow release of the contaminant, as modeled by CORMIX, is not a true representation of the intermittent releases expected from the vessels in the harbor. The decay coefficient is time dependent. An small increase in the duration of the discharge is likely to cause a large decrease in the coliform count. Therefore, the predicted value is likely to be exaggerated.

An advection-dispersion model was used to estimate a peak concentration of 13.0 CFU/100mL as the plume reaches the mudflat. The coefficient of longitudinal dispersion used in this model is relatively conservative. Therefore, the concentration of the plume is probably less than the predicted value.

The result of the additional modeling using the decay coefficient and revised flow pattern shows that a vessel release might be sufficiently reduced in concentration within the channel reaches. The revised modeling contradicts the former results. This shows the importance of verification of the assumptions that are used in modeling. The latest results are likely to be more representative of the actual situation. Therefore, it is probable that the clamflats would not be contaminated.

The addendum is included with a copy of the original report. Your consideration of me for this study is appreciated. Please feel free to call at 862-3623 if you have any questions or comments.

Sincerely,

Holly C. Gallagher

Holly Clark Gallagher

Table of Contents

A1. Introduction:

Description of the Revisions

The flow pattern as the tide fills the harbor has been revised. The first modeling assumed that the water filled the channel and then flowed at a velocity of 10cm/s in a westerly direction over the mudflat. The revision includes a combination of a southerly flow at 30cm/s that continues in the channel with the westerly flow of 10cm/s over the mudflat. The resultant flow direction is south-southwest at a velocity of 32cm/s.

A decay coefficient of 10 day^{-1} was estimated at Jackson Laboratory. No decay was assumed to occur in the first modeling. The die-off of bacteria in cold seawater is significant and was taken into account in the revised modeling. The decay coefficient is based on disappearance of pathogens due to die-off. It is influenced by the type of bacteria, salinity, temperature, and light intensity. Decay coefficients for fresh water have been measured at 0.12 to 26 d^{-1} for coliform. The bacterial decay in seawater is more rapid.

A2. Modeling Studies:

CORMIX Modeling

The change in flow direction was incorporated in the CORMIX model by adjusting the orientation of the multiport diffuser. The first stage was run using the 300m (984 ft) long diffuser with 35 ports laid along the centerline of the channel to approximate 35 vessels moored in a similar manner. The initial effluent concentration of 5426700 CFU/100mL was used as before. The only revision was the addition of the decay coefficient to the initial parameters. The discharge from the diffuser is shown to be fully mixed vertically and laterally in the channel in approximately 2 hours. The estimated concentration is 2190 CFU/mL as shown in the CORMIX output (Appendix C). The total CFU discharged by the 35 vessels was reduced using the decay coefficient. The new total that remains after the 2.14 hrs from Stage 1 was used in a mass balance equation to determine the size of the discharge ports for the second stage (Appendix C).

The configuration of the 'river' for Stage 2 matches the flow direction as determined by the revised velocity vector. This results in the multiport diffuser being angled at 18.4°, measured counterclockwise from the ambient flow. The width of the river assumes that the left bank is 48m (157 ft) from the nearest end of the diffuser as it is aligned with the center of the channel. The depth is assumed at 1m (3.3 ft) deep and the width at 500m (1640 ft), which are not changed from the original run. The distance to the mudflat is assumed to be 154m (505 ft) along the 'river' as measured from the center of the diffuser. The decay coefficient was added to the model parameters for the second stage. The result of Stage 2 shows that the effluent plume will be vertically and laterally fully mixed before it reaches the clam beds. The estimated concentration of the plume is 0.0176 CFU/100mL (Appendix C). This is well below the limitation of 14 CFU/100mL.

The CORMIX model simulates a slow release of the effluent over a number of hours. The decay coefficient is time dependent. A small increase in the duration of the contaminant in the seawater causes a large decrease in the concentration. The flow rate in the harbor during flood tide is fast enough to move a discharge from the mooring to the mudflat in approximately 8 minutes. Therefore, the result of the CORMIX model is likely to predict values that are too low.

Advection-Dispersion Evaluation of a Slug Injection

An advection-convection model was used to estimate the peak concentration of the plume as it reaches the mudflat. The McQuivey and Keefer method was used to estimate the magnitude of the longitudinal dispersion coefficient at 55.7 m^2/s (Appendix D). This value may be underestimated which would result in a conservative estimate of the plume concentration. The plume is assumed to move in the south-southwesterly direction at 32cm/s. The distance from the mooring to the edge of the mudflat along the flow path is 154m (505 ft). The estimated time elapsed from discharge at the mooring to the mudflat is 8 minutes. The decay coefficient of 10 d^{-1} was used in this model. The result of 13 CFU/100mL is below the limitation of 14 CFU/100mL.

A3. Conclusion:

The revised modeling using a decay coefficient and a different flow pattern shows that a vessel release might be considerably reduced in concentration within the channel. The flow direction was changed from west to south-southwest so the plume travels farther before it reaches the mudflat. The decay of the bacteria reduces the coliform count which reduces the concentration. In addition, the plume is more diluted as it moves farther away from the source. Therefore, the die-off of the bacteria and dilution may reduce the coliform count below contamination limits before the plume reaches the clam beds.

The CORMIX results appear to be exaggerated by the long time factor. The slug injection model is conservative and estimates a value below the contamination limit. The accuracy of the advection-dispersion model depends on the determination of the longitudinal dispersion coefficient. The value of the dispersion coefficient could be verified using a tracer study. A laboratory study of the bacteria in a sample of the Hampton Harbor water held at an appropriate temperature could be used to verify the decay coefficient.

The results of the revised modeling are considerably different from the former results. The revision to the advection-dispersion model appears to be a better representation of the actual situation at Hampton Harbor. The vessel discharge into the harbor is likely to be adequately reduced and diluted within the channel to prevent contamination of the mudflats.

Appendix C

CORMIX -- CORNELL MIXING ZONE EXPERT SYSTEM -- CORMIX

SITE Name Seabrook Harbor Mudflat — Date: 6/28/95
Design **CASE** Multiport discharge w/ decay — Prepared by: HCGallagher
DOS **FILE NAME** STAGE1MD (w/o extension)

AMBIENT DATA:

Water body depth 3 m
Depth at discharge 3 m
Ambient flowrate (28) m³/s or: Ambient velocity 0.1 m/s
Manning's n 0.014 or: Darcy-Weisbach f ____
Wind speed 2 m/s

Water body is bounded/unbounded
If bounded: Width 96 m
Appearance 1/2/3

Density data:

UNITS: Density...kg/m³ / Temperature...°C

Water body is fresh/salt water
If fresh: Specify as density/temp. values
If uniform: Average density/temp. 1010.5
If stratified: Density/temp. at surface ____
Stratification type A/B/C — Density/temp. at bottom ____
If B/C: Pycnocline height ____ m — If C: Density/temp. jump ____

DISCHARGE DATA: Specify **geometry** for CORMIX1 or 2 or 3

SUBMERGED SINGLE PORT DISCHARGE -- CORMIX1

Nearest bank is on left/right — Distance to nearest bank ____ m
Vertical angle THETA ____ ° — Horizontal angle SIGMA ____ °
Port diameter ____ m or: Port area ____ m²
Port height ____ m

SUBMERGED MULTIPORT DIFFUSER DISCHARGE -- CORMIX2

Nearest bank is on left/right — Distance to one endpoint 48 m
Diffuser length 300 m — to other endpoint 48 m
Total number of openings 35
Port diameter 0.051 m with contraction ratio 1
Diffuser arrangement/type unidirectional / staged / alternating or vertical B, A
Alignment angle GAMMA 0 ° — Horizontal angle SIGMA ____ °
Vertical angle THETA 90 ° — Relative orientation BETA ____ °
Port height 0.99 m — A = holes (single ports)

BUOYANT SURFACE DISCHARGE -- CORMIX3

Discharge located on left/right bank — Configuration flush/protruding/co-flowing
Horizontal angle SIGMA ____ ° — If protruding: Dist. frm bank ____ m
Depth at discharge ____ m — Bottom slope ____ °
If rectangular Width ____ m or: If circular Diameter ____ m
discharge channel: Depth ____ m — pipe: Bottom invert depth ____ m

Effluent: Flow rate 0.00714 m³/s or: Effluent velocity ____ m/s
Effluent density 1010.15 kg/m³ or: Effluent temperature ____ °C
Heated discharge? yes/no — If yes: Heat loss coefficient ____ W/m²,°C
Concentration units CFU-PER-100mL — Effluent concentration 5426700
Conservative substance? yes/no — If no: Decay coefficient 10 /day

MIXING ZONE DATA:

Is effluent toxic? yes/no — If yes: CMC value 14
CCC value 14
WQ stand./conventional poll.? yes/no — If yes: value of standard ____
Any mixing zone specified? yes/no — If yes: distance ____ m
or width ____ % or m
Region of interest 1000 m — or area ____ % or m²
Grid intervals for display 6

```
CORMIX2 PREDICTION FILE:
2222222222222222222222222222222222222222222222222222222222222222222222222222222
                    CORNELL MIXING ZONE EXPERT SYSTEM
Subsystem CORMIX2:                                           Subsystem version:
 Submerged Multiport Diffuser Discharges     CMX2 v.2.10              May 1993
-------------------------------------------------------------------------------
-------------------------------------------------------------------------------
CASE DESCRIPTION
 Site name/label:          Seabrook^Harbor^Mudflat
 Design case:              Multiport^discharge^with^decay
 FILE NAME:                cormix\sim\stage1md.cx2
 Time of Fortran run:      06/29/95--08:48:47

ENVIRONMENT PARAMETERS (metric units)
 Bounded section
 BS     =      96.00 AS     =     288.00 QA     =      28.80
 HA     =       3.00 HD     =       3.00
 UA     =       .100 F      =       .011 USTAR = .3651E-02
 UW     =      2.000 UWSTAR= .2198E-02
 Uniform density environment
 STRCND=  U          RHOAM = 1010.5000

DIFFUSER DISCHARGE PARAMETERS (metric units)
 DITYPE=alternating parallel
 BETYPE=alternating without fanning
 BANK   =  LEFT       DISTB =        .00 YB1    =      48.00 YB2    =      48.00
 LD     =     300.00 NOPEN =    35        SPAC   =       8.82
 D0     =       .051 A0     =       .002 H0     =        .99
 GAMMA =        .00 THETA =      90.00
 SIGMA =        .00 BETA   =      90.00
 U0     =       .100 Q0     =       .007        = .7140E-02
 RHO0   = 1010.1500 DRHO0 = .3500E+00 GP0     = .3396E-02
 C0     = .5427E+07 CUNITS=  CFU-per-100mL
 IPOLL =  2          KS     = .0000E+00 KD     = .1160E-03

DIFFUSER PARAMETERS WITH IMAGE EFFECTS (metric units)
 The bank/shore proximity effect is accounted for by the following flow
 variables and definitions of length scales and parameters.
 LD     =     300.00 Q0     =       .014 (Q0    = .1428E-01)

FLUX VARIABLES - PER UNIT DIFFUSER LENGTH (metric units)
 q0     = .9500E-04  m0     = .2370E-05  j0     = .8067E-07  SIGNJ0=       1.0
 Associated 2-d length scales (meters)
 lQ=B   =       .001 lM     =        .13  lm     =        .00
 lmp    = 99999.00  lbp    = 99999.00  la     = 99999.00

FLUX VARIABLES - ENTIRE DIFFUSER (metric units)
 Q0     = .1428E-01  M0     = .7111E-03  J0     = .2420E-04
 Associated 3-d length scales (meters)
 LQ     =        .41  LM     =        .89  Lm     =        .35  Lb     =        .05
                                           Lmp    = 99999.00  Lbp    = 99999.00

NON-DIMENSIONAL PARAMETERS
 FR0    =     110.99  FRD0   =       7.58  R      =        .99
 (slot)                (port/nozzle)

FLOW CLASSIFICATION
 222222222222222222222222222222222222222222
 2  Flow class (CORMIX2)       =    MU1H    2
```

```
 2  Applicable layer depth HS =     3.00  2
 2222222222222222222222222222222222222222

MIXING ZONE / TOXIC DILUTION / REGION OF INTEREST PARAMETERS
 CO     = .5427E+07  CUNITS=  CFU-per-100mL
 NTOX   =  1         CMC    = .1400E+02  CCC    =  CSTD
 NSTD   =  1         CSTD   = .1400E+02
 REGMZ  =  0
 XINT   =   1000.00  XMAX   =   1000.00

X-Y-Z COORDINATE SYSTEM:
  because of bank/shore proximity, the ORIGIN is located directly
   at the LEFT  bank/shore.
  the bank/shore acts as a plane of symmetry for   the predicted
  plume geometry.
    X-axis points downstream, Y-axis points to left, Z-axis points upward.
NSTEP =  6 display intervals per module
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD201: DIFFUSER DISCHARGE MODULE

 Profile definitions:
   BV = Gaussian 1/e (37%) half-width, in vertical plane normal to trajectory
   BH = top-hat half-width, in horizontal plane normal to trajectory
   S  = hydrodynamic centerline dilution
   C  = centerline concentration (includes reaction effects, if any)

       X        Y        Z        S        C        BV       BH
      .00      .00      .99      1.0  .543E+07     .00   150.00

END OF MOD201: DIFFUSER DISCHARGE MODULE
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD211: WEAKLY DEFLECTED PLANE JET IN CROSSFLOW

 CROSSFLOWING DISCHARGE

 This flow region is INSIGNIFICANT in spatial extent and will be by-passed.

END OF MOD211: WEAKLY DEFLECTED PLANE JET IN CROSSFLOW
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD222: STRONGLY DEFLECTED PLANE PLUME IN CROSSFLOW

 Profile definitions:
   BV = Gaussian 1/e (37%) half-width, in vertical plane normal to trajectory
   BH = top-hat half-width, in horizontal plane normal to trajectory
   S  = hydrodynamic centerline dilution
   C  = centerline concentration (includes reaction effects, if any)

       X        Y        Z        S        C        BV       BH
      .00      .00      .99      1.0  .543E+07     .00   150.00
    78.84      .00     1.24    473.3  .105E+05     .15   150.15
   157.68      .00     1.49    945.6  .478E+04     .30   150.30
   236.52      .00     1.74   1417.9  .291E+04     .45   150.45
   315.36      .00     2.00   1890.2  .199E+04     .60   150.60
   394.20      .00     2.25   2362.5  .145E+04     .75   150.75
   473.04      .00     2.50   2834.8  .111E+04     .90   150.90
 Cumulative travel time =        4730. sec
```

END OF MOD222: STRONGLY DEFLECTED PLANE PLUME IN CROSSFLOW

BEGIN MOD243: DENSITY CURRENT DEVELOPING ALONG PARALLEL DIFFUSER LINE

The plume for this parallel diffuser interacts with the surface/pycnocline or the bottom, and a DENSITY CURRENT forms.
Note: The starting x-coordinate of the developing plume will be shifted upstream.

Profile definitions:
BV = top-hat thickness, measured vertically
BH = top-hat half-width, measured horizontally in y-direction
ZU = upper plume boundary (Z-coordinate)
ZL = lower plume boundary (Z-coordinate)
S = hydrodynamic average (bulk) dilution
C = average (bulk) concentration (includes reaction effects, if any)

X	Y	Z	S	C	BV	BH
323.04	.00	3.00	2834.8	.111E+04	.90	.90
373.04	.00	3.00	4009.0	.738E+03	3.00	.95
423.04	.00	3.00	4009.0	.696E+03	3.00	.99
473.04	.00	3.00	4009.0	.657E+03	3.00	1.04
523.04	.00	3.00	4009.0	.620E+03	3.00	1.09
573.04	.00	3.00	4009.0	.585E+03	3.00	1.14
623.04	.00	3.00	4009.0	.552E+03	3.00	1.19

Cumulative travel time = 7730. sec

END OF MOD243: DENSITY CURRENT DEVELOPING ALONG PARALLEL DIFFUSER LINE

** End of NEAR-FIELD REGION (NFR) **

Recall that the plume is symmetric to the bank/shore on which the centerline (X-axis) is located.

The LIMITING DILUTION (given by ambient flow/discharge ratio) is: 1009.4
This value is below the computed dilution of 4009.0 at the end of the NFR.
Mixing for this discharge configuration is constrained by the ambient flow.

The previous module predictions are unreliable since the limiting dilution cannot be exceeded for this diffuser in deep unstratified layer.

A subsequent module (MOD281) will predict the properties of the cross-sectionally fully mixed plume with limiting dilution and will compute a POSSIBLE UPSTREAM WEDGE INTRUSION.

BEGIN MOD281: MIXED PLUME/BOUNDED CHANNEL/POSSIBLE UPSTREAM WEDGE INTRUSION

The DOWNSTREAM flow field for this unstable shallow water discharge is VERTICALLY FULLY MIXED.
The mixing is controlled by the limiting dilution = 1009.4

Channel DENSIMETRIC FROUDE NUMBER (FCHAN) for this mixed flow = 31.47

No upstream wedge intrusion takes place since FCHAN exceeds the critical value of 0.7.

X	Y	Z	S	C	BV	BH	ZU	ZL
623.04	.00	3.00	1009.4	.219E+04	3.00	96.00	3.00	.00

Cumulative travel time = 7730. sec

VERTICALLY AND LATERALLY FULLY MIXED over layer depth: END OF SIMULATION!

END OF MOD281: MIXED PLUME/BOUNDED CHANNEL/POSSIBLE UPSTREAM WEDGE INTRUSION

CORMIX2: Submerged Multiport Diffuser Discharges End of Prediction File

22222222222222222222222222222222222222222222222222222222222222222222222222222

C-6

```
CORMIX SESSION REPORT:
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
                  CORMIX: CORNELL MIXING ZONE EXPERT SYSTEM
                      CORMIX v.2.10           May 1993
SITE NAME/LABEL:                 Seabrook Harbor Mudflat
  DESIGN CASE:                   Multiport discharge with decay
  FILE NAME:                     stage1md
Using subsystem CORMIX2:         Submerged Multiport Diffuser Discharges
  Start of session:              06/29/95--08:43:27
*******************************************************************************
SUMMARY OF INPUT DATA:
-------------------------------------------------------------------------------
AMBIENT PARAMETERS:
  Cross-section                            = bounded
  Width                            BS      =          96 m
  Channel regularity                       = 1
  Ambient flowrate                 QA      =       28.80 m^3/s
  Average depth                    HA      =           3 m
  Depth at discharge               HD      =           3 m
  Ambient velocity                 UA      =          .1 m/s
  Darcy-Weisbach friction factor   F       =      0.0106
    Calculated from Manning's n            =        .014
  Wind velocity                    UW      =           2 m/s
Stratification Type                STRCND  = U
  Surface density                  RHOAS   =      1010.5 kg/m^3
  Bottom density                   RHOAB   =      1010.5 kg/m^3
-------------------------------------------------------------------------------
DISCHARGE PARAMETERS:              Submerged Multiport Diffuser Discharge
  Diffuser type                    DITYPE  = alternating parallel
  Diffuser length                  LD      = 300 m
  Nearest bank                             = left
  Diffuser endpoints               YB1     =      48 m;    YB2 =      48 m
  Number of openings               NOPEN   =          35
  Spacing between risers/openings  SPAC    =        8.82 m
  Port/Nozzle diameter             D0      =        .051 m
  Equivalent slot width            B0      =      0.0002 m
  Total area of openings           A0      =      0.0020 m^2
  Discharge velocity               U0      =        0.09 m/s
  Total discharge                  Q0      =      .00714 m^3/s
  Discharge port height            H0      =         .99 m
  Nozzle arrangement               BETYPE  = alternating without fanning
  Diffuser alignment angle         GAMMA   =           0 deg
  Vertical discharge angle         THETA   =        90.0 deg
  Horizontal discharge angle       SIGMA   =         0.0 deg
  Relative orientation angle       BETA    =        90.0 deg
  Discharge density                RHO0    =     1010.15 kg/m^3
  Density difference               DRHO    =      0.3500 kg/m^3
  Buoyant acceleration             GP0     =       .0034 m/s^2
  Discharge concentration          C0      =        5426700 CFU-per-100mL
  Surface heat exchange coeff.     KS      =           0 m/s
  Coefficient of decay             KD      =    0.000116 /s
-------------------------------------------------------------------------------
FLUX VARIABLES PER UNIT DIFFUSER LENGTH:
  Discharge (volume flux)          q0      =    0.000095 m^2/s
  Momentum flux                    m0      =    0.000004 m^3/s^2
  Buoyancy flux                    j0      =           0 m^3/s^3
-------------------------------------------------------------------------------
DISCHARGE/ENVIRONMENT LENGTH SCALES :
  lq  =      0.00 m          lm  =      0.00 m          lM =      0.12 m
```

```
 lm' =    99999.0 m          lb' =    99999.0 m          la =    99999.0 m
 (These refer to the actual discharge/environment length scales.)
-----------------------------------------------------------------------------
NON-DIMENSIONAL PARAMETERS:
 Slot Froude number                 FR0     =     110.99
 Port/nozzle Froude number          FRD0    =       7.58
 Velocity ratio                     R       =       0.99
-----------------------------------------------------------------------------
MIXING ZONE / TOXIC DILUTION ZONE / AREA OF INTEREST PARAMETERS:
 Toxic discharge                            = yes
 CMC concentration                  CMC     =                  14 CFU-per-100mL
 CCC concentration                  CCC     =                  14 CFU-per-100mL
 Water quality standard                     = given by CCC value
 Regulatory mixing zone                     = no
 Region of interest                         =       1000.00 m downstream
*****************************************************************************
HYDRODYNAMIC CLASSIFICATION:
 *------------------------*
 | FLOW CLASS  =    MU1H  |
 *------------------------*
 This flow configuration applies to a layer corresponding to the full water
 depth at the discharge site.
 Applicable layer depth = water depth =            3 m
*****************************************************************************
MIXING ZONE EVALUATION (hydrodynamic and regulatory summary):
-----------------------------------------------------------------------------
X-Y-Z Coordinate system:
 Origin is located at the bottom below the port center:
           0.0 m from the left bank/shore.
-----------------------------------------------------------------------------
NEAR-FIELD REGION (NFR) CONDITIONS :
Note: The NFR is the zone of strong initial mixing.  It has no regulatory
 implication.  However, this information may be useful for the discharge
 designer because the mixing in the NFR is usually sensitive to the
 discharge design conditions.
 Pollutant concentration at edge of NFR =        552.1489 CFU-per-100mL
 Dilution at edge of NFR                =      4008.9
 NFR Location:                        x =      623.04 m
   (centerline coordinates)           y =         .00 m
                                      z =        3.00 m
 NFR plume dimensions:       half-width =        1.18 m
                              thickness =        3.00 m
-----------------------------------------------------------------------------
Buoyancy assessment:
 The effluent density is less than the surrounding ambient water
 density at the discharge level.
 Therefore, the effluent is POSITIVELY BUOYANT and will tend to rise towards
 the surface.
************************ TOXIC DILUTION ZONE SUMMARY ************************
Criterion maximum concentration (CMC)   =                14 CFU-per-100mL
Corresponding dilution                  =           .0

The CMC value was not encountered within the specified simulation distance.
 Plume dilution values are too low to meet CMC.
********************** REGULATORY MIXING ZONE SUMMARY ***********************
No RMZ has been specified.
The CCC for the toxic pollutant was not encountered within the predicted
 plume region.
********************* FINAL DESIGN ADVICE AND COMMENTS **********************
CORMIX2 uses the TWO-DIMENSIONAL SLOT DIFFUSER CONCEPT to represent
```

the actual three-dimensional diffuser geometry. Thus, it approximates the details of the merging process of the individual jets from each port/nozzle.
In the present design, the spacing between adjacent ports/nozzles (or riser assemblies) is of the order of, or less than, the local water depth so that the slot diffuser approximation holds well.
Nevertheless, if this is a final design, the user is advised to use a final CORMIX1 (single port discharge) analysis, with discharge data for an individual diffuser jet/plume, in order to compare to the present near-field prediction.

DIFFUSER DESIGN DETAILS: Because of the alternating arrangement of the opposing nozzles/ports, the AVERAGE VERTICAL ANGLE (THETA) has been set to 90 deg. This represents a ZERO NET HORIZONTAL MOMENTUM FLUX for the entire diffuser.

This parallel diffuser lies in CLOSE PROXIMITY to the bank (shoreline). The shoreline will act as a REFLECTING BOUNDARY for the flow field. This effect has been represented by doubling all flow variables.

REMINDER: The user must take note that HYDRODYNAMIC MODELING by any known technique is NOT AN EXACT SCIENCE.
Extensive comparison with field and laboratory data has shown that the CORMIX predictions on dilutions and concentrations (with associated plume geometries) are reliable for the majority of cases and are accurate to within about +-50% (standard deviation).
As a further safeguard, CORMIX will not give predictions whenever it judges the design configuration as highly complex and uncertain for prediction.

```
*****************************************************************************
DESIGN CASE:                     Multiport discharge with decay
FILE NAME:                       stage1md
Subsystem CORMIX2:               Submerged Multiport Diffuser Discharges
END OF SESSION/ITERATION:        06/30/95--09:08:43
XXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXXX
```

The Department of Civil Engineering
College of Engineering and Physical Sciences
The University of New Hampshire
Kingsbury Hall
33 College Road
Durham, New Hampshire 03824-3591

Project/Problem Set: Cormix Modeling
Detail/Problem: Stage 2 w/Decay Coeff.
Class: ______ Prof: ______

Calc. by: H.C. Gallagher
Date: 6/29/95
Chck. by:
Date:

Given: 2×10^9 CFU per vessel
35 vessels
Initial concentration = 2190 CFU/100 mL
Decay coeff = $10\ d^{-1} = 0.000116\ s^{-1}$
Velocity components are 0.1 m/s toward mudflat from center line of channel and 0.3 m/s along centerline of channel

Find: Port diameter for 35 equal sized ports if discharge is continuous for 4 hrs

① finding total CFU after 7730 sec (from stage 1)

$$M = (2\times10^9\,\text{CFU})(35)\exp\left[(-0.000116\ s^{-1})(7730\ \text{sec})\right] = 2.86\times10^{10}$$

② finding volume, $\forall$

$$\forall = \frac{2.86\times10^{10}}{2190\ \text{CFU}/100\text{mL}}\left(1\times10^{-6}\ m^3/\text{mL}\right) = 1304\ m^3$$

③ finding total discharge, Q

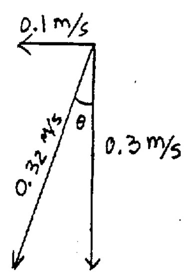
$$Q = 1304\ m^3/4\,\text{hr}(3600\ s/\text{hr}) = 0.0906\ m^3/s$$

④ finding magnitude of velocity

$$V = (0.1^2 + 0.3^2)^{1/2} = 0.32\ m/s$$

⑤ finding area of Port, A

$$A = \frac{Q}{V} = \frac{0.0906\ m^3/s}{(0.32\ m/s)(35)} = 0.0081\ m^2/\text{port}$$



⑥ finding diameter of Port, d

$$d = \sqrt{\frac{4A}{\pi}} = 0.101\ m$$

⑦ finding angle of flow to diffuser, θ

$$\theta = \tan^{-1}(0.1/0.3) = 18.4^\circ$$

CORMIX -- CORNELL MIXING ZONE EXPERT SYSTEM -- CORMIX

SITE Name	Seabrook Harbor Mud flat	Date:	6/28/95
Design CASE	Multiport discharge w/ decay	Prepared by:	H.C. Gallagher
DOS FILE NAME	Stage 2D (w/o extension)		

AMBIENT DATA:

Water body depth	1 m	Water body is	bounded/unbounded
Depth at discharge	1 m	If bounded: Width	500 m
		Appearance	1/2/3
Ambient flowrate	____ m³/s or:	Ambient velocity	0.32 m/s
Manning's n	0.014 or:	Darcy-Weisbach f	
Wind speed	2 m/s		

Density data: UNITS: Density...kg/m³ / Temperature...°C

Water body is	fresh/salt water	If fresh: Specify as	density/temp. values
If uniform:		Average density/temp.	1010.5
If stratified:		Density/temp. at surface	
Stratification type	A/B/C	Density/temp. at bottom	
If B/C: Pycnocline height	____ m	If C: Density/temp. jump	

DISCHARGE DATA:

Specify **geometry** for CORMIX1 or 2 or 3

SUBMERGED SINGLE PORT DISCHARGE -- CORMIX1

Nearest bank is on	left/right	Distance to nearest bank	____ m
Vertical angle THETA	____ °	Horizontal angle SIGMA	____ °
Port diameter	____ m or:	Port area	____ m²
Port height	____ m		

SUBMERGED MULTIPORT DIFFUSER DISCHARGE -- CORMIX2

Nearest bank is on	left/right	Distance to one endpoint	143 m
Diffuser length	300 m	to other endpoint	48 m
Total number of openings	35		
Port diameter	0.101 m	with contraction ratio	1
Diffuser arrangement/type	unidirectional / staged / alternating or vertical		
Alignment angle GAMMA	18.4 °	Horizontal angle SIGMA	0 coflowing °
Vertical angle THETA	0 horiz °	Relative orientation BETA	18.4 °
Port height	0.33 m		

BUOYANT SURFACE DISCHARGE -- CORMIX3

Discharge located on	left/right bank	Configuration	flush/protruding/co-flowing
Horizontal angle SIGMA	____ °	If protruding: Dist. frm bank	____ m
Depth at discharge	____ m	Bottom slope	____ °
If rectangular Width	____ m or:	If circular Diameter	____ m
discharge channel: Depth	____ m	pipe: Bottom invert depth	____ m

Effluent: Flow rate	0.0906 m³/s or:	Effluent velocity	____ m/s
Effluent density	1010.5 kg/m³ or:	Effluent temperature	____ °C
Heated discharge?	yes/no	If yes: Heat loss coefficient	____ W/m²,°C
Concentration units	CFU per 100ml	Effluent concentration	2190
Conservative substance?	yes/no	If no: Decay coefficient	10 /day

MIXING ZONE DATA:

Is effluent toxic?	yes/no	If yes: CMC value	14
		CCC value	14
WQ stand./conventional poll.?	yes/no	If yes: value of standard	
Any mixing zone specified?	yes/no	If yes: distance	____ m
		or width	____ % or m
Region of interest	5000 m	or area	____ % or m²
Grid intervals for display	6		

```
CORMIX2 PREDICTION FILE:
22222222222222222222222222222222222222222222222222222222222222222222222222222
                        CORNELL MIXING ZONE EXPERT SYSTEM
Subsystem CORMIX2:                                          Subsystem version:
 Submerged Multiport Diffuser Discharges    CMX2 v.2.10              May 1993
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
CASE DESCRIPTION
 Site name/label:           Seabrook^Harbor^Mudflat
 Design case:               Multiport^discharge^with^decay
 FILE NAME:                 cormix\sim\stage2d .cx2
 Time of Fortran run:       06/29/95--14:57:54

ENVIRONMENT PARAMETERS (metric units)
 Bounded section
 BS      =     500.00  AS      =     500.00  QA      =    160.00
 HA      =       1.00  HD      =       1.00
 UA      =       .320  F       =       .015  USTAR = .1403E-01
 UW      =      2.000  UWSTAR= .2198E-02
 Uniform density environment
 STRCND=  U            RHOAM = 1010.5000

DIFFUSER DISCHARGE PARAMETERS (metric units)
 DITYPE=staged parallel
 BETYPE=staged
 BANK   =  LEFT        DISTB =          .00  YB1     =     48.00  YB2     =     143.00
 LD      =     300.00  NOPEN =   35          SPAC    =      8.82
 D0      =       .101  A0      =       .008  H0      =       .33
 GAMMA =       18.40  THETA =          .00
 SIGMA =         .00  BETA    =     18.40
 U0      =       .323  Q0      =       .091          = .9060E-01
 RHO0    = 1010.5000  DRHO0 = .0000E+00  GP0     = .0000E+00
 C0      = .2190E+04  CUNITS=  CFU-per-100mL
 IPOLL = 2            KS      = .0000E+00  KD      = .1160E-03

DIFFUSER PARAMETERS WITH IMAGE EFFECTS (metric units)
 The bank/shore proximity effect is accounted for by the following flow
 variables and definitions of length scales and parameters.
 LD      =     284.67  Q0      =        .181 (Q0     = .1812E+00)

FLUX VARIABLES - PER UNIT DIFFUSER LENGTH (metric units)
 q0      = .1342E-02  m0      = .9755E-04  j0      = .0000E+00  SIGNJ0=       1.0
 Associated 2-d length scales (meters)
 lQ=B    =       .004 lM      =  99999.00  lm      =       .00
 lmp     =  99999.00  lbp     =  99999.00  la      =  99999.00

FLUX VARIABLES - ENTIRE DIFFUSER (metric units)
 Q0      = .1812E+00  M0      = .2777E-01  J0      = .0000E+00
 Associated 3-d length scales (meters)
 LQ      =        .75  LM      =  99999.00  Lm      =        .76  Lb      =        .00
                                            Lmp     =  99999.00  Lbp     =  99999.00

NON-DIMENSIONAL PARAMETERS
 FR0     =  99999.00  FRD0    =  99999.00  R       =      1.00
 (slot)               (port/nozzle)

FLOW CLASSIFICATION
 2222222222222222222222222222222222222222222
 2  Flow class (CORMIX2)        =    MU7    2
```

```
 2  Applicable layer depth HS =      1.00  2
 2222222222222222222222222222222222222222222

MIXING ZONE / TOXIC DILUTION / REGION OF INTEREST PARAMETERS
 C0     = .2190E+04  CUNITS=  CFU-per-100mL
 NTOX   =  1         CMC    = .1400E+02  CCC    =  CSTD
 NSTD   =  1         CSTD   = .1400E+02
 REGMZ  =  0
 XINT   =    5000.00  XMAX   =    5000.00

X-Y-Z COORDINATE SYSTEM:
  because of bank/shore proximity, the ORIGIN is located directly
   at the LEFT  bank/shore.
  the bank/shore acts as a plane of symmetry for   the predicted
  plume geometry.
    X-axis points downstream, Y-axis points to left, Z-axis points upward.
NSTEP =  6 display intervals per module
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD202: DISCHARGE MODULE (STAGED DIFFUSER)

 Profile definitions:
   BV = Gaussian 1/e (37%) half-width, in vertical plane normal to trajectory
   BH = Gaussian 1/e (37%) half-width in horizontal plane normal to trajectory
   S  = hydrodynamic centerline dilution
   C  = centerline concentration (includes reaction effects, if any)

       X         Y        Z        S        C         BV        BH
   -142.33      .00      .33      1.0  .219E+04     .05       .05

END OF MOD202: DISCHARGE MODULE (STAGED DIFFUSER)
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD274: ACCELERATION ZONE OF STAGED DIFFUSER

 In this laterally contracting zone the diffuser plume becomes VERTICALLY FULLY
  MIXED over the entire layer depth (HS =     1.00m).
   Full mixing is achieved after a plume distance of about five
   layer depths from the diffuser.

 Profile definitions:
   BV = layer depth (vertically mixed)
   BH = Gaussian 1/e (37%) half-width in horizontal plane normal to trajectory
   ZU = upper plume boundary (Z-coordinate)
   ZL = lower plume boundary (Z-coordinate)
   S  = hydrodynamic centerline dilution
   C  = centerline concentration (includes reaction effects, if any)

       X         Y        Z        S        C         BV        BH
   -142.33      .00     1.00      1.0  .219E+04    1.00        .00
    -97.32      .00     1.00      2.8  .133E+03    1.00      14.24
    -52.30      .00     1.00      2.8  .223E+02    1.00      28.48
** CMC HAS BEEN FOUND **
 The pollutant concentration in the plume falls below CMC value of  .140E+02
   in the current prediction interval.
 This is the extent of the TOXIC DILUTION ZONE.
** WATER QUALITY STANDARD OR CCC HAS BEEN FOUND **
 The pollutant concentration in the plume falls below water quality standard
   or CCC value of  .140E+02 in the current prediction interval.
 This is the spatial extent of concentrations exceeding the water quality
```

```
standard or CCC value.
  -7.28        .00     1.00      2.8  .374E+01   1.00     42.72
  37.74        .00     1.00      2.8  .627E+00   1.00     56.96
  82.76        .00     1.00      2.8  .105E+00   1.00     71.20
 127.78        .00     1.00      2.8  .176E-01   1.00     85.44
Cumulative travel time =         92384. sec

END OF MOD274: ACCELERATION ZONE OF STAGED DIFFUSER
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD251: DIFFUSER PLUME IN CO-FLOW

 Phase 1: Vertically mixed, Phase 2: Re-stratified

 This flow region is INSIGNIFICANT in spatial extent and will be by-passed.

END OF MOD251: DIFFUSER PLUME IN CO-FLOW
-----------------------------------------------------------------------------
** End of NEAR-FIELD REGION (NFR) **

 The initial plume WIDTH values in the next far-field module will be
  CORRECTED by a factor   .10 to conserve the mass flux in the far-field!

 Recall that the plume is symmetric to the bank/shore on which the centerline
   (X-axis) is located.
-----------------------------------------------------------------------------
BEGIN MOD241: BUOYANT AMBIENT SPREADING

 Plume is ATTACHED to LEFT  bank/shore.
   Plume width is now determined from LEFT  bank/shore.

 Discharge is non-buoyant or weakly buoyant.
   Therefore BUOYANT SPREADING REGIME is ABSENT.

END OF MOD241: BUOYANT AMBIENT SPREADING
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
BEGIN MOD261: PASSIVE AMBIENT MIXING IN UNIFORM AMBIENT

  Vertical diffusivity (initial value)    =  .281E-02 m^2/s
  Horizontal diffusivity (initial value) =  .351E-02 m^2/s

 The passive diffusion plume is VERTICALLY FULLY MIXED at beginning of region.

 Profile definitions:
   BV = Gaussian s.d.*sqrt(pi/2) (46%) thickness, measured vertically
      = or equal to layer depth, if fully mixed
   BH = Gaussian s.d.*sqrt(pi/2) (46%) half-width,
        measured horizontally in Y-direction
   ZU = upper plume boundary (Z-coordinate)
   ZL = lower plume boundary (Z-coordinate)
   S  = hydrodynamic centerline dilution
   C  = centerline concentration (includes reaction effects, if any)

 Plume Stage 2 (bank attached):
        X           Y        Z          S        C        BV        BH       ZU       ZL
     127.78       .00     1.00       2.8  .176E-01   1.00      1.56     1.00      .00
     939.82       .00     1.00       9.7  .371E-02   1.00      5.52     1.00      .00
    1751.85       .00     1.00      13.5  .200E-02   1.00      7.65     1.00      .00
    2563.89       .00     1.00      16.4  .122E-02   1.00      9.30     1.00      .00
```

```
  3375.93      .00    1.00    18.9  .792E-03   1.00    10.70    1.00     .00
  4187.96      .00    1.00    21.1  .529E-03   1.00    11.94    1.00     .00
  5000.00      .00    1.00    23.1  .360E-03   1.00    13.06    1.00     .00
 Cumulative travel time =     107610. sec

 Simulation limit based on maximum specified distance =   5000.00 m.
   This is the REGION OF INTEREST limitation.

END OF MOD261: PASSIVE AMBIENT MIXING IN UNIFORM AMBIENT
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
Because of the fairly LARGE SPACING between adjacent risers/nozzles/ports,
  the above results may be unreliable in the immediate near-field of
  the diffuser.
A SUBSEQUENT APPLICATION OF CORMIX1 IS RECOMMENDED to provide more detail
  for one of the individual jets/plumes in the initial region
before merging.
-----------------------------------------------------------------------------
-----------------------------------------------------------------------------
CORMIX2: Submerged Multiport Diffuser Discharges       End of Prediction File
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CORMIX SESSION REPORT:

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                 CORMIX: CORNELL MIXING ZONE EXPERT SYSTEM
                     CORMIX v.2.10              May 1993
SITE NAME/LABEL:                  Seabrook Harbor Mudflat
  DESIGN CASE:                    Multiport discharge with decay
  FILE NAME:                      stage2d
Using subsystem CORMIX2:          Submerged Multiport Diffuser Discharges
  Start of session:               06/29/95--14:40:12
************************************************************************
SUMMARY OF INPUT DATA:
------------------------------------------------------------------------
AMBIENT PARAMETERS:
  Cross-section                                = bounded
  Width                               BS       =          500 m
  Channel regularity                           = 1
  Ambient flowrate                    QA       =          160 m^3/s
  Average depth                       HA       =            1 m
  Depth at discharge                  HD       =            1 m
  Ambient velocity                    UA       =          .32 m/s
  Darcy-Weisbach friction factor      F        =       0.0153
    Calculated from Manning's n                =        0.014
  Wind velocity                       UW       =            2 m/s
Stratification Type                   STRCND   = U
  Surface density                     RHOAS    =       1010.5 kg/m^3
  Bottom density                      RHOAB    =       1010.5 kg/m^3
------------------------------------------------------------------------
DISCHARGE PARAMETERS:                 Submerged Multiport Diffuser Discharge
  Diffuser type                       DITYPE   = staged parallel
  Diffuser length                     LD       = 300 m
  Nearest bank                                 = left
  Diffuser endpoints                  YB1      =       48 m;    YB2 =     143 m
  Number of openings                  NOPEN    =           35
  Spacing between risers/openings     SPAC     =         8.82 m
  Port/Nozzle diameter                D0       =         .101 m
  Equivalent slot width               B0       =       0.0009 m
  Total area of openings              A0       =       0.0080 m^2
  Discharge velocity                  U0       =         0.32 m/s
  Total discharge                     Q0       =        .0906 m^3/s
  Discharge port height               H0       =          .33 m
  Nozzle arrangement                  BETYPE   = staged
  Diffuser alignment angle            GAMMA    =         18.4 deg
  Vertical discharge angle            THETA    =            0 deg
  Horizontal discharge angle          SIGMA    =            0 deg
  Relative orientation angle          BETA     =         18.4 deg
  Discharge density                   RHO0     =       1010.5 kg/m^3
  Density difference                  DRHO     =            0 kg/m^3
  Buoyant acceleration                GP0      =        .0000 m/s^2
  Discharge concentration             C0       =             2190 CFU-per-100mL
  Surface heat exchange coeff.        KS       =            0 m/s
  Coefficient of decay                KD       =     0.000116 /s
------------------------------------------------------------------------
FLUX VARIABLES PER UNIT DIFFUSER LENGTH:
  Discharge (volume flux)             q0       =     0.001342 m^2/s
  Momentum flux                       m0       =     0.000207 m^3/s^2
  Buoyancy flux                       j0       =            0 m^3/s^3
------------------------------------------------------------------------
DISCHARGE/ENVIRONMENT LENGTH SCALES :
  lq  =       0.00 m          lm  =       0.00 m          lM =    99999.0 m
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  lm' =    99999.0 m          lb' =    99999.0 m          la =    99999.0 m
  (These refer to the actual discharge/environment length scales.)
-----------------------------------------------------------------------------
NON-DIMENSIONAL PARAMETERS:
  Slot Froude number                FR0     =     99999.0
  Port/nozzle Froude number         FRD0    =     99999.0
  Velocity ratio                    R       =        1.00
-----------------------------------------------------------------------------
MIXING ZONE / TOXIC DILUTION ZONE / AREA OF INTEREST PARAMETERS:
  Toxic discharge                           = yes
  CMC concentration                 CMC     =                14 CFU-per-100mL
  CCC concentration                 CCC     =                14 CFU-per-100mL
  Water quality standard                    = given by CCC value
  Regulatory mixing zone                    = no
  Region of interest                        =       5000.00 m downstream
*****************************************************************************
HYDRODYNAMIC CLASSIFICATION:
  *------------------------*
  | FLOW CLASS   =     MU7 |
  *------------------------*
  This flow configuration applies to a layer corresponding to the full water
  depth at the discharge site.
  Applicable layer depth = water depth =           1 m
*****************************************************************************
MIXING ZONE EVALUATION (hydrodynamic and regulatory summary):
-----------------------------------------------------------------------------
X-Y-Z Coordinate system:
  Origin is located at the bottom below the port center:
           0.0 m from the left bank/shore.
-----------------------------------------------------------------------------
NEAR-FIELD REGION (NFR) CONDITIONS :
Note: The NFR is the zone of strong initial mixing.  It has no regulatory
  implication.  However, this information may be useful for the discharge
  designer because the mixing in the NFR is usually sensitive to the
  discharge design conditions.
  Pollutant concentration at edge of NFR =          .0176 CFU-per-100mL
  Dilution at edge of NFR                =        2.7
  NFR Location:                        x =      127.78 m
    (centerline coordinates)           y =         .00 m
                                       z =        1.00 m
  NFR plume dimensions:       half-width =       85.44 m
                               thickness =        1.00 m
-----------------------------------------------------------------------------
Buoyancy assessment:
  The effluent density is equal or about about equal to the surrounding
  ambient water density at the discharge level.
  Therefore, the effluent behaves essentially as NEUTRALLY BUOYANT.
-----------------------------------------------------------------------------
Near-field instability behavior:
  The diffuser flow will experience instabilities with full vertical mixing
  in the near-field.
  There may be benthic impact of high pollutant concentrations.
-----------------------------------------------------------------------------
FAR-FIELD MIXING SUMMARY:
  Plume becomes vertically fully mixed at       127.78 m downstream.
*********************** TOXIC DILUTION ZONE SUMMARY ************************
Recall: The TDZ corresponds to the three (3) criteria issued in the USEPA
  Technical Support Document (TSD) for Water Quality-based Toxics Control,
  1991 (EPA/505/2-90-001).
  Criterion maximum concentration (CMC)  =              14 CFU-per-100mL
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 Corresponding dilution                    =       156.4
The CMC was encountered at the following plume position:
 Plume location:                        x =      -32.14 m
   (centerline coordinates)             y =         .00 m
                                        z =        1.00 m
 Plume dimensions:             half-width =       34.85 m
                                thickness =        1.00 m
 CRITERION 1: This location is within 50 times the discharge length scale of
              Lq = 0.089486 m.
 +++++ The discharge length scale TEST for the TDZ has been SATISFIED. ++++++

 CRITERION 2: This location is within 5 times the ambient water depth
              HD =          1 m.
 ++++++++++ The ambient depth TEST for the TDZ has been SATISFIED.+++++++++++

 CRITERION 3: No RMZ has been defined.  Therefore, the Regulatory Mixing zone
              test for the TDZ cannot be applied.
 The diffuser discharge velocity is equal to         0.32 m/s.
   This is less than the minimum of 3.0 m/s recommended in the TSD.
 +++ The discharge velocity RECOMMENDATION for the TDZ has NOT been met. ++++

 *** All three CMC criteria for the TDZ are SATISFIED for this discharge. ***
********************** REGULATORY MIXING ZONE SUMMARY ***********************
No RMZ has been specified.
However:
The CCC was encountered at the following plume position:
The CCC for the toxic pollutant was encountered at the following
  plume position:
  CCC                                      =              14 CFU-per-100mL
  Corresponding dilution                   =       156.4
  Plume location:                       x =      -32.14 m
    (centerline coordinates)            y =         .00 m
                                        z =        1.00 m
  Plume dimensions:            half-width =       34.85 m
                                thickness =        1.00 m
********************* FINAL DESIGN ADVICE AND COMMENTS **********************
CORMIX2 uses the TWO-DIMENSIONAL SLOT DIFFUSER CONCEPT to represent
  the actual three-dimensional diffuser geometry.  Thus, it approximates
  the details of the merging process of the individual jets from each
  port/nozzle.
In the present design, the spacing between adjacent ports/nozzles
  (or riser assemblies) is somewhat greater (in the range between
  three times to ten times) the local water depth.  It is unlikely
  that sufficient lateral interaction of adjacent jets will
  occur in the near-field.  However, the individual jets/plumes may merge
  soon after in the intermediate-field or in the far-field.

CORMIX2 may have LIMITED APPLICABILITY for this discharge situation.
  The results may be somewhat unrealistic in the near-field (minimum
  dilution may be overpredicted), but appear to be applicable for the
  intermediate- and far-field processes.
The user is advised to use a subsequent CORMIX1 (single port discharge)
  analysis, using discharge data for an individual diffuser jet/plume,
  in order to compare to the present near-field prediction.
-----------------------------------------------------------------------------
This parallel diffuser lies in CLOSE PROXIMITY to the bank (shoreline). The
  shoreline will act as a REFLECTING BOUNDARY for the flow field. This effect
  has been represented by doubling all flow variables.
-----------------------------------------------------------------------------
REMINDER:  The user must take note that HYDRODYNAMIC MODELING by any known
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technique is NOT AN EXACT SCIENCE.
Extensive comparison with field and laboratory data has shown that the CORMIX predictions on dilutions and concentrations (with associated plume geometries) are reliable for the majority of cases and are accurate to within about +-50% (standard deviation).
As a further safeguard, CORMIX will not give predictions whenever it judges the design configuration as highly complex and uncertain for prediction.
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******************************************************************************
DESIGN CASE:                     Multiport discharge with decay
FILE NAME:                       stage2d
Subsystem CORMIX2:               Submerged Multiport Diffuser Discharges
END OF SESSION/ITERATION:        06/30/95--09:12:02
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Appendix D

The Department of Civil Engineering
College of Engineering and Physical Sciences
The University of New Hampshire
Kingsbury Hall
33 College Road
Durham, New Hampshire 03824-3591

Project/Problem Set: Slug Injection
Detail/Problem: with Decay Coefficient
Class: ______ Prof: ______

Sheet: D-1 of 1
Calc. by: H.C. Gallagher
Date: 6/28/95
Chck. by: ______
Date: ______

Given: Mass of Slug $= 2 \times 10^9$ CFU
Velocity = 0.3 m/s along channel and 0.1 m/s across channel
Channel is 101.2 m wide × 3 m deep × 500 m Long (normal to flow)
Decay coefficient = $K = 10\ d^{-1}$

Find: Concentration of fecal coliform using a stream dispersion equation

Theory: McQuivey and Keefer dispersion coefficient equation

$$D_L = 0.058 \frac{Q}{(S_o W)} = 0.058 \frac{vA}{S_o W} = 0.058 \frac{v d}{S_o}$$

Stream dispersion equation for concentration

$$c(x,t) = \frac{M \exp[-Kt]}{A(4\pi D_L t)^{1/2}} \exp^{-}\left[\frac{(x-vt)^2}{4D_L t}\right]$$ (Metcalf & Eddy, 1972 p1214)

Assumptions: $S_o = 0.001$
Decay coefficient is applied to reduce concentration prior to calculating final concentration
Formula is valid for reach not less than 7 stream widths.

① finding magnitude of net velocity, v

$$v = (0.1^2 + 0.3^2)^{1/2} = 0.32 \text{ m/s}$$

② finding D_L

$$D_L = 0.058 (0.32)(3)/0.001 = 55.7 \text{ m}^2/\text{s}$$

③ finding distance to clamflat along velocity vector

$$x = (48 \text{ m})(0.32 \text{ m/s})/(0.1 \text{ m/s}) = 154 \text{ m}$$

④ finding peak concentration @ x = 154 m from slug injection

$A = \frac{154}{7} \times 3 = 25 \text{ m}^2$ $\quad x - vt = 0 \therefore \exp^{-}\left[\frac{(x-vt)^2}{4D_L t}\right] = 1$
$V = 0.32$ m/s
$t = 481$ s

$$c(154\text{m}, 481\text{s}) = \frac{(2\times10^9 \text{ CFU})(10^{-4} \text{ m}^3/100\text{mL})(\exp[-10d^{-1}(481\text{s})(1.157\times10^{-5} \text{ d/s})])}{(25\text{m}^2)(4\pi(55.7 \text{ m}^2/\text{s})(481\text{s}))^{1/2}} = 13.0 \frac{\text{CFU}}{100\text{mL}}$$